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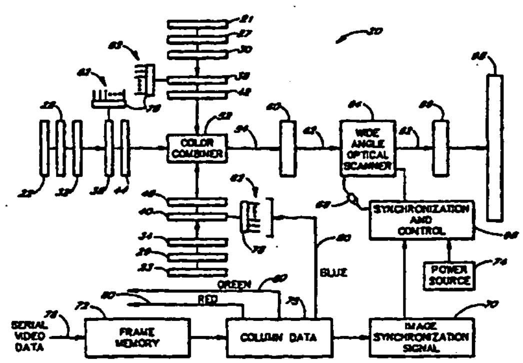

(57) Abstract

A time synchronized digital modulation (TSDM) image display system (10, 20) that achieves a high level of gray scale resolution while utilizing binary light modulators. By producing color digitally, extremely accurate and consistent color reproduction is achieved. In the preferred embodiment the system includes a light source (21, 22, 23) producing a light beam of optical radiation that is divided into a plurality of beamlets which are modulated in a light modulator (36, 38, 40, 48) having M rows by N columns of modulator elements. Each modulator element (50) has an "on" state and an "off" state that is controllable by a set of image signals. In the "on" state a predetermined beamlet is transmitted by the modulator element, and in the "off" state the beamlet is prevented from being transmitted. When all of the modulator elements are in the "on" state, the intensity of the modulator output varies so that there is a different intensity of light transmitted by each modulator element. The modulated light beam is then scanned across a viewing surface (98). The modulator is synchronised with the scanner (64) so that during each scan a predetermined pattern of "on" and "off" states is present in the modulator, thus projecting a predetermined total intensity level of light onto each pixel of the viewing surface. Due to the speed at which the scanning occurs, a viewer perceives only the total integrated light intensity for each pixel, thereby producing a predetermined gray level (and thus color level) on each image pixel based on the particular pattern of "on" and "off" states of the modulator elements. When spectrally pure lasers are used for the light sources, the TSDM system makes standardizable digital color reproduction possible.

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PROJECTION DISPLAY WITH GRADATION LEVELS OBTAINED BY MODULATION OF BEAMLETS

Background of the Invention

Field of the Invention

This invention relates to image display systems and more particularly to an image display system which generates digital color utilizing laser light and which enables a binary light modulator to achieve gray level picture quality.

Description of the Related Art

There is an ever-increasing demand for display systems that can transfer high quality information and images to users in a variety of settings. In particular, there is a strong need for high quality display systems that have high brightness, high frame rates and high resolution in a compact, cost effective and efficient manner.

In video projectors, two basic principles, light-modulation and direct emission, are commonly used. In a light-modulation design, a beam of light passes through an optical array which is capable of switching individual display pixels on or off. Liquid crystal display (LCD) panels are common light modulators. Other, more exotic modulators, such as oil films and deformable micro-mirrors, are also available. Direct-emission projectors emit their own light. The most common direct-emission device is the CRT projector, which is used in home TV projectors and in high power versions for large screen industrial use.

As the resolution requirements of high definition television (HDTV) and multimedia displays increase, CRT-based projectors reach some basic physical limits. A breakthrough is necessary to extend the resolution and brightness limits of this projection technology. Unfortunately, there are very few viable direct-emission technologies, so designers have looked for other ways to project video and computer information. The result is a host of light-modulation projectors using many different techniques. However, such light modulation projectors share a set of common problems, one being the need for an efficient light source which maximizes the amount of available light. Another issue is the need to pass conventional light sources through a small spatial light modulator which raises a number of problems. The design issues associated with these needs are difficult and complex, and in many cases they directly limit the achievable results. For example, parameters which must be optimized include luminous efficiency, size, brightness, resolution, reliability, color gamut, contrast and dynamic range. Yet existing technologies are close to reaching their ultimate potential due to fundamental limitations.

To better understand the nature of the limitations associated with previous technologies, it is instructive to briefly review the operating characteristics of principal contenders in the video projection arena. These can be identified as CRT projectors, liquid crystal light valve projectors, passive-matrix LCD panels, active-matrix LCD panels, electroluminescence, solid state deformable light modulators, electron beam pumped semiconductor lasers, and laser based systems.

CRT Projectors: Projection CRTs are similar to conventional monochrome CRTs, except that they are operated at much higher beam currents. Color systems are built using three independent CRT systems, each with its own lens. The user must make periodic convergence adjustments to bring the three beams into color registration.

Attempts to produce single-lens projectors, where the three color tubes are internally converged at the factory, have not been widely accepted, and automatic converging systems are just beginning to be introduced.

Light Valve Projectors: Light valve projectors have been developed to overcome some of the deficiencies of CRT projectors. An advantage of light valve systems is that the light source and modulating elements are decoupled. Light valve projectors base on the electron beam oil film light valve were developed over 25 years ago. In such systems, an oil film is used as the image source. Intensity of the projected light is controlled by the amplitude of the deformation of the oil film. However, these systems are very complex, bulky, expensive and difficult to set up and maintain.

An alternative to the oil film approach is the LCD light valve. Here the LCD matrix is not used a simple shutter that reduces the input light. Instead, a stimulus response to the input signal is used to activate the LCD material, which then is coupled to a separate output light source. Extremely high resolutions (5000 x 7000) have been achieved via the LCD approach. However, due to the thermal inertia, the writing rate is very slow at this resolution, requiring 3.5 minutes to update a display using two 40 milliwatt lasers. Ultra high resolution is thus offset by very slow writing speed and very high cost.

Passive-Matrix LCD Panels: A simpler method for using an LCD panel as a light modulator is to interpose the panel between a light source and the projection optics. Such panels can be activated by either of two approaches, either passive-matrix or active-matrix. In both passive and active drive technologies, the LCD cells are arranged in a matrix of rows and columns, and are driven by row and column driver circuits. In a passive-matrix drive system, the LCD cell alone exists at each intersection. A time-multiplexing scheme is used to energize each of the LCD cells in the matrix. Unfortunately, the slow response time of passive-matrix panels makes them unsuitable for displaying quickly changing information such as television signals. Also, crosstalk between LCD cells is a significant disadvantage.

Active-Matrice LCD Panels: In these systems, an active-matrix panel contains a switching device such as a thin film transistor (TFT), and a storage element (capacitor), in addition to the LCD cell at every LCD element site. Each switch/capacitor acts as a "sample-hold" (S/H) circuit for the briefly appearing pulses from the multiplexed drive system. Each LCD cell, driven by its own S/H circuit, is thus decoupled from the other LCD cells, minimizing crosstalk. Furthermore, active-matrix LCD cells can be formulated to respond quickly. Update times under 50 milliseconds are easily achieved with active-matrix panels. However, active-matrix panels are not easy to manufacture, requiring an impressive range of challenging technologies. The overall yield is the product of a series of process steps, each of which incur significant losses.

Solid State Deformable Light Modulators: An approach presently being developed with solid state deformable light modulators is represented by the digital micromirror device (DMD). This device comprises an array of tiny mirrors, each supported by an electrostrictive or a piezoelectric actuator layer. A mirror for each modulator element is tilted individually and precisely. The incoming light is reflected off the modulator element mirror and passes through a projection optic. An off modulator element reflects light to a knife-edge and cannot pass through the optic. Because of the small angular tilts of the individual mirrors (+ 10 degrees), the light source used to

illuminate the mirrors must be nearly collimated, which limits the brightness available when arc lamps are used. The reflectivity of the aluminum mirror face, defects in the miniature mirror surfaces, and component inefficiencies limit the throughput of this device to less than 50%. Also, the discrete modulator elements lead to problems with tiling and distortion correction, as with all discrete modulator element techniques.

Electron Beam Pumped Semiconductor Laser (EBPSL): EBPSL's appear to be an attractive technology for large screen displays. The ability to generate color display with 50,000 lumens is highly attractive for large screen simulators and for electronic cinema applications. However, concerns exist regarding the stability of this technology to lower brightness applications (map and command control systems) and to display systems in which power and size requirements must be balanced with brightness. Also, the semiconductor laser screens of current devices require cooling to cryogenic temperatures (100 to 150° K) for efficient optical performance. In addition, the x-ray flux from the 65 to 75 kV accelerating voltages can pose a significant health hazard. The high voltage and cooling requirements yield a display device with an efficiency reaching 0.8 lumens/W. Thus a 50,000 lumen display requires 62.5 kW of power. Even with improvements to the semiconductor screens, to the drive voltages and to the cooling method, it seems likely that EBPSL's will remain prohibitive for many applications due to their size, weight and power requirements.

Laser Based Systems: With the introduction of gas lasers in the early 1970's, major companies began programs to produce full color laser based displays. These systems employed argon-ion and krypton-ion gas lasers, acousto-optic or electro-optic modulators, high speed polygon scanners, and galvanometric deflection to produce NTSC and higher resolutions. The limitations encountered in further developing these systems were the large size and cooling requirements of gas laser systems, the high cost of components (particularly the acousto-optic modulators and polygon scanners), as well as the objectionable speckle in the images produced. The systems actually built demonstrated the superiority of laser systems in producing high brightness and resolution. However, their size and power consumption made hopes of commercialization remote.

Early laser displays, which used a single beam in each of the primary colors, were independently amplitude modulated to achieve the requisite gray levels combined to produce a full color pixel, and then scanned in two dimensions to display the final image. A fast spinning polygonal mirror provided the horizontal raster, while a galvanometric scanner provided the vertical field rate scan. Extrapolating this form of scanning architecture to an HDTV standard places formidable requirements upon the spinning polygon; rates approaching 100,000 RPM are required for a 20 facet polygon. While not impossible, polygons of this type are very expensive and bulky and require vacuum enclosures to avoid heating and mechanical warping. More recent laser displays of this type are exemplified by U.S. patent 5,534,950. The system disclosed in this patent reduces the required speed by using a plurality of laser beams in parallel. However, this system still needs an optical polygon scanner.

Other problems relate to the amplitude fluctuations associated with laser sources. Amplitude instabilities in frequency-doubled solid-state lasers can arise from processes such as longitudinal mode beating. This results in amplitude fluctuations in the kHz to MHz frequency regime. Since these instabilities are on the order of the line scan

rate, they can manifest themselves as image artifacts in the scanned image. Also, the pixel dimensions are defined by the laser source itself, requiring additional attention to be paid to the spatial mode of the laser resonator.

In many systems such as those described above, it is desired that the system be capable of generating an image having a relatively high number of gray levels in order to produce a realistic image. Heretofore, this has usually necessitated the use of analog light modulators, which have a number of inherent limitations. The brightness level achieved by an analog modulator is usually imprecise. Also, current analog modulators are relatively slow. This places a limitation on the scan rate which can be used. High scan rates are usually desired to achieve higher resolution. Furthermore, the use of analog modulators restricts the possible resolution by limiting the number of modulator elements. This is because, as the number of modulator elements in analog modulators increases, the cost of the modulator rises significantly. This is primarily due to low production yields for analog modulators having smaller sized elements. Furthermore, the number of possible gray scales is limited by the accuracy and speed of the analog modulator. As a result, typical analog modulators are capable of generating images having generally eight bits of gray scale data. This inherently limits the quality of the video image and prevents the generation of extremely realistic video images.

Other drawbacks found in conventional color display systems result from the fact that these technologies all are based upon analog phenomena for the display of color. Whether it be the electron-beam-excited phosphors in TV tubes or the LCD modulation of a color-filtered lamp, the colors that we perceive are formulated in an analog fashion. Furthermore, since the light sources to which analog modulation is applied are neither spectrally pure nor immune to variation from one display to another, currently there is no absolute standard relative to the colors of any display. Compounding the problem is the fact that when an analog system degrades, colors shift due to the different relative intensities of the three color channels. As a result, when an individual views an object on a display, the colors viewed will generally not match those of another individual viewing a different display. This situation has seriously limited potential applications of color display technologies. For example, it is not possible today to ascertain the precise color of a product advertised on television or on the Internet. In areas where color is of importance, such as the selection of a garment, this problem limits the usefulness of these media as a shopping vehicle. Consequently, as long as these limitations of analog color display systems persist, significant areas of commercial potential within the video communication arena will remain untapped.

There are a number of problems with analog modulation schemes which makes them inherently imprecise generators of color. first, the light sources used to create full-color images are not spectrally invariant. Also, the specific red, green and blue coordinates associated with these sources, are typically not widely separated with respect to the International Commission on Illumination (CIE) chromaticity diagram. This wide separation is necessary to ensure that essentially every hue perceptible to the human eye is reproduced faithfully. Also, in prior systems the relative intensities of the red, green and blue sources are not proportioned precisely so as to match a universal standard. Moreover, in prior systems the fractional power that propagates from each color source to each pixel of a projected image cannot be maintained in the proper proportionality throughout the entire dynamic range of the image.

Accordingly, it would be desirable to provide a color display technology that avoids the above-discussed disadvantages of analog modulation schemes. In particular, it would be desirable to provide a color display technology that uses spectrally invariant light sources that are widely separated with respect to the CIE chromaticity diagram so that every hue perceptible to the human eye is faithfully reproduced. Also, it would be desirable to provide such a color display technology in which the relative intensities of the red, green and blue sources are proportioned precisely so as to match a universal standard throughout the entire dynamic range of the image.

It would also be desirable to provide an image projection system that can generate a large number of gray levels without requiring an analog modulator, which increases the possible ray scale resolution.

It would also be desirable to provide an image projection system that is capable of very high resolution while not requiring an extremely high number of modulator elements. It is also desirable to provide an image projection system with the above features in which the scan rate can be easily altered to match that of the source, which can be readily adapted to multiple picture formats.

Summary of the Invention

The present invention generally comprises a color display system based on a concept called Time Synchronized Digital Modulation (TSDM), which is a digital technique for generating an image. When combined with red, green and blue laser sources TSDM makes it possible to implement a concept referred to as "digital color." Digital color makes it possible to display color in a consistent, uniform, standardized and precise manner. It does this by combining spectrally invariant laser sources with a digital technique for generating color (TSDM), thereby avoiding the many disadvantages of analog color modulator schemes. By utilizing only binary light modulators, the present invention achieves a high level of gray scale resolution utilizing the "time persistence" of the visual system to successively build up the desired intensity level. If lasers were used as light sources this technique makes possible digital color wherein consistent, accurate and standardized color can be generated across various display systems. In particular, during each frame of the projection process, each pixel within the image is sequentially printed by red, green and blue sets of binary "ones" and "zeros." Hence, the binary code associated with each pixel defines, in digital form, the precise color and brightness of that pixel.

In general, the TSDM technique of the present invention utilizes a source of signals representing an image, a source of light, a spatial light modulator responsive to the signals, and a synchronized scanning system that operates so that the total intensity of each given pixel of the image on a viewing surface is represented by a series of discrete light level signals displayed in sequence over a pixel on a viewing surface. When added together, these discrete levels equal the total intensity level for each pixel in the image on the viewing surface.

In a preferred embodiment, the present invention comprises a light source that produces optical radiation including a plurality of beamlets directed to a light modulating unit having M rows by N columns of modulator elements. The optical radiation may have a continuous intensity distribution, in which case each beamlet is defined by the aperture of the respective modulator element in the array. In other embodiments, a continuously distributed beam may be divided into beamlets by, for example, a microlens array. In other embodiments, the light source could comprise multiple light sources, each providing one or more beamlets. Preferably, each beamlet has a predetermined

intensity, and as applied to the rows, each beamlet has an intensity different from the adjoining beamlet. A source of modulation signals representing an image is also provided. Each modulator element has an "on" state and an "off" state that is controllable by image signals. In the "on" state, a beamlet is transmitted by a modulator element and in the "off" state, the light beam is prevented from being transmitted. An optical scanning unit scans the modulated beamlets across a viewing surface. A synchronizer is used to synchronize the signals with the scanner in such a way that during each scan a predetermined pattern of "on" and "off" states is generated in the modulating unit, thereby projecting a predetermined total intensity level of light onto each pixel of the viewing surface. The system also includes optical elements for imaging the scanned beam onto a viewing surface.

The entire image is generated on the viewing surface at a high enough speed that a viewer perceives the integrated sum of all of the scans instead of individual scans. Since the viewer perceives each pixel as the total integrated light intensity, a predetermined gray level is perceived based on the particular pattern of "on" and "off" states of the light modulating elements. This is because the human visual system integrates incoming light over 20 to 30 milliseconds, and during this time several bits of the intensity level are written on the same pixel. The viewer will then perceive only the total sum of these intensity levels because the entire image will be scanned in matter of microseconds. In the preferred embodiment, the beamlets applied to the spatial light modulator have a binary weighted distribution, so that each of the N columns represents binary intensity levels such that each successive column transmits twice the intensity of the previous column. Where N = 8, for example, an 8-bit gray level image can thereby be generated by the pattern of "on" and "off" states for each of the eight modulator elements in a given row. By combining the TSDM technique with spectrally invariant laser light sources that are widely separated on the CIE chromaticity diagram, digital color imagery is achieved. This results in a consistent, uniform and accurate color display that allows the standardization of color display among various displays.

The present invention overcomes a number of limitations of prior display systems. For example, to achieve high resolution, a large number of modulator elements is required. In single laser beam scanning systems this means a high scanning rate. The present invention reduces complexity versus laser beam scanning systems by eliminating the need for a high rate optical scanner. This results in higher efficiency, lower costs and lighter weight. Furthermore, as compared to spatial light modulator systems, the present invention can reduce the number of required modulator elements in the light modulator by an order of magnitude or more. It also permits very high resolution and allows the scan rate, as well as the image format, to be easily altered. In addition, the invention utilizes binary modulators in a way that yields high fidelity, greater dynamic range, lower cost, fewer modulator elements and a more compact design.

Brief Description of the Drawings

The objects, advantages and features of this invention will be more readily appreciated from the following detailed description, when read in conjunction with the accompanying drawing, in which:

Figure 1 is a conceptual block diagram of the Time Synchronized Digital Modulation system of the present invention;

Figure 2 is a conceptual schematic diagram of a preferred embodiment of an RGB display system that implements the invention;

Figure 3A and 3B are diagrams of a light modulator and a viewing surface, respectively, in accordance with the present invention;

Figure 4A and 4B are diagrams of the modulator of Figure 3 illustrating successive steps in the scanning process over time;

Figure 5 is a diagram of a binary illumination intensity profile at the modulator in the preferred embodiment of the present invention;

Figure 6 is a diagram of a light modulator in accordance with another embodiment of the system of the invention;

Figure 7A and 7B are diagrams of an alternative modulator intensity profile of the invention having fault tolerance;

Figure 8 is a diagram of an alternative light modulator of the invention having scalable light levels;

Figure 9 is a diagram of a candidate beam weighing device that generates a binary illumination profile similar to that shown in Figure 5, along with a modulator array which can be used with the present invention; and

Figure 10 is a conceptual schematic diagram of a full color embodiment of the invention.

Detailed Description of the Preferred Embodiments

The generation of a multiplicity of gray levels in image projection systems utilizing light modulators has generally required the use of analog modulators. However, the disadvantages of analog modulators, as described previously, have limited their application in advanced image projection systems requiring high resolution, lower costs and smaller packaging. The present invention provides a technique called Time Synchronized Digital Modulation (TSDM) which permits the generation of a multiplicity of gray levels from binary modulators. This allows image display systems built according to the present invention to achieve a high number of gray levels while at the same time making use of the numerous advantages of binary light modulators. These advantages include lower costs, higher switching speeds and compact design. When coupled with properly chosen laser light sources, a TSDM system allows the generation of "digital color" that is consistent, accurate and standardizable.

Furthermore, the present invention permits a higher number of gray levels to be generated than has been achieved using existing analog light modulators, making possible even higher color resolution than was previously possible. For example, this invention may be easily employed to provide eight, ten twelve or even more bits of gray level discrimination. In addition, due to the scanning techniques employed with the invention, the number of modulator elements in the light modulator is greatly reduced as compared to prior systems. This further reduces the cost and improves the manufacturability of the system, while also increasing the resolution.

Referring now to Figure 1, a functional block diagram of the TSDM system of the invention is illustrated. TSDM system 10 includes source 12 of image data. Light source 13 provides illumination in the form of a plurality of beamlets, each having a discrete predetermined light intensity. The image data is directed to modulation system 14 that modulates the light intensity of the beamlets so that the total intensity of each given pixel in the image is

represented by a plurality of discrete light intensity levels. The light levels are arranged spatially and temporally by modulation system 14 such that when the modulated beamlets are imaged onto a given pixel, added together they equal the total intensity level for each given pixel. Details of the operation of the modulation system are described in various embodiments of the present invention set out below. The output of the modulation system is then directed to scanning system 16 that is synchronized with the modulation system to convert the modulation system output into a representation that successively generates a desired total intensity level from a plurality of beamlets incident upon each given pixel in the image. The light generated by scanning system 16 is then directed to a viewing surface to create image 18.

Figure 2 is a functional block diagram of one embodiment 20 of TSDM image display system 10 of the present invention. The system includes three linear light sources 21, 22, 23. It should be noted that light sources 21, 22 and 23 may comprise one of many different kinds of light sources. The chief requirement is that each source be capable of producing a sufficiently intense light beam that can be shaped into the required configuration of beamlets. For example, the light sources may be solid state lasers, LEDs, laser diodes, or arc lamps. The best choice will depend on the particular constraints (cost, space, etc.,) of the particular application. Multiple light sources may be used to reach a desired intensity level. However, it will be appreciated that with the progressive development of ever more powerful solid state laser sources, the required number of laser sources can be reduced.

In one embodiment of the present invention the light sources comprise microlasers and pumping diode arrays such as described in U.S. patent 5,534,950, which is incorporated by reference herein. It will be appreciated that the microlasers overcome many of the problems with previous high intensity light sources used for video projection systems which had efficiency problems and often employed exotic and expensive mechanical systems. In particular, since the microlasers do not require bulky deflection systems and optics, and because of their inherent miniaturization, very bright and compact projectors are made possible using this laser projector technology.

It should be noted that in one embodiment in the above-identified patent, the lasers can be intensity modulated directly by means of an electrical current applied to the individual diode laser pumping sources. While this configuration avoids the necessity of an analog light modulator, it requires a high number of light sources in the microlasers, as well as the necessity of a high speed polygon scanner, adding manufacturing and operational costs. In contrast, in the present invention, microlasers or other light sources are preferably used as constant intensity light sources, although in other embodiments modulated light sources can be used. In the disclosed embodiment light modulation occurs through the use of binary light modulators in combination with a unique scanning process. These sources also have the advantage of their spectral purity and optimized wavelengths to generate a full gamut of colors.

Also, it should be noted by using lasers such as those disclosed in patent 5,534,950, the light sources are spectrally invariant, which facilitates the creation of standardizable digital color, as described above. Optimally, the three laser wavelengths should be chosen to be widely separated on the CIE chromaticity diagram to ensure that every hue perceptible to the human eye can be reproduced faithfully.

In more detail, optical radiation from sources 21, 22 and 23 is directed to light shaping devices 27, 28 and 29, respectively. The light shaping devices each may comprise an optical element, or a diffractive element capable of forming the light from the source into a plurality of beamlets having an overall size and shape to match the light modulator array. The beamlets need not have clearly defined boundaries: for example, the light shaping device may provide a continuous intensity distribution to the modulation system which defines the beamlets by the aperture of the modulator elements. In one embodiment employing lasers to provide optical radiation, light shaping devices 27, 28 and 29 will transform one or more generally circular beams of light into a line of light that has an approximately constant intensity across the narrow dimension of the line. In some embodiments, the line of light could be applied directly to the modulator. Of course, the nature of the light shaping device will depend on the size and shape of the beam generated by the light source.

Beam weighing devices 30, 32, 34 may be used to transform the optical radiation from light shaping devices 27, 28, 29 into the proper intensity distribution for the TSDM system. For example, if a binary weighing distribution is required a beam multiplexing device, as illustrated in Figure 9, can be used to generate the preferred intensity distribution. This beam weighing device maintains the uniform line of light in one dimension, while generating a binarily decreasing intensity distribution in the other dimension. This is performed by decreasing by half the intensity of the light in subsequent passes. The result is parallel beams with half (or double) the intensity of the neighboring beam. The different beam weighing devices could generate many different intensity distributions ranging from binary, to Gaussian to a uniform flat top (rectangle) that could be used in conjunction with the modulator illustrated in Figure 6.

Beam weighing devices 30, 32 and 34 receive the light from the light shaping device and create a beamlet intensity distribution that varies across the narrow dimension of the line of light from the light shaping devices. Any combination of conventional techniques could be used to implement the beam weighing devices. In the preferred embodiment the intensity distribution is binary weighted as will be described in more detail with respect to Figure 5, for example. Beam weighing devices 30, 32 and 34 then respectively direct and focus the beamlets onto light modulators 36, 38 and 40, which comprise individually modulated elements. For example, the individual modulator elements of the light modulators may be less than fifteen to greater than fifty microns in size. After passing through the light modulator elements the light then enters field lens arrays 42, 44 and 46, which collect the light and relay it to the rest of the imaging system.

Light modulator 48, which is representative of light modulators 36, 38 and 40, is shown in Figure 3. The light modulator, in this embodiment, may be a pseudolinear binary ferro-electric liquid crystal (FELC) modulator which operates in a transmissive mode. However, it will be appreciated that the advantages of the present invention may be achieved by the use of reflective modulators, which may be preferred for some modulator technologies. Also, it should be noted that any other high rate electro-optic binary switching devices and spatial light modulators (SLMS) can be employed for modulators 36, 38 and 40. These include lead lanthanum ziconate titanate (PLZT), digital micro-mirror device (DMD), grating light valve (GLV), or other high rate binary modulating technology. Further, analog modulators switched between "on" and "off" states could also be used if their switching speed is high enough.

In the preferred embodiment shown in Figure 3, modulator 48 comprises a quasilinear 8 x 2048 modulator which generates a 2560 x 2048 image. Each modulator element 50 is individually addressable to switch between a transmissive "on" state and a nontransmissive "off" state. In accordance with the techniques of the present invention, the width of the modulator has N modular elements and the length has M modular elements. Where N = 8 as in the preferred embodiment, eight bits of gray scale will be achievable in the manner discussed below. While this will result in an extremely high resolution image with very good dynamic range, it is important to note that there is no inherent limit on the number for N. Thus, for example, by simply increasing N to twelve, the present invention can be utilized to generate twelve bits of dynamic range in each color. With twelve bits of dynamic range, the invention could produce images that exceed the human visual system's color discrimination ability. That is, such a 12-bit device could produce images as close to real in appearance as any display image generator known to date. Further, by using the appropriate laser sources, as described above, the TSDM technique can precisely proportion the basic red, green and blue sources throughout the dynamic range of the image to achieve standardized digital color.

The additional bits of gray scale can also be used for "correction bits." These correction bits could compensate for non-uniformity in the illumination system, in the modulator or in other system components. For example to achieve a true ten-bit image, twelve columns could be used so that the eleventh and twelfth column in the modulator could be used to "fine tune" the system to achieve the uniformity required for such high quality images. The correction can be performed in a set-up and calibration procedure and/or during operation using feedback sensor 68.

Referring again to Figure 2, the modulated beamlets pass from modulators 36, 38 and 40 and through field lenses 42, 44 and 46, and then enter color combiner 52 that combines the three color beamlets into single output beamlet 54. In the preferred embodiment, combiner 52 may comprise a three-input and one output optical combiner such as prism combiner 31 shown in Figure 3 in the above-incorporated by reference patent 5,534,950. It should be noted that the configuration of the red, green and blue light sources will determine the design of the combiner and that other configurations and positions are possible in addition to the one shown in Figure 1 of the patent identified above.

Different configurations will simply require different combiner designs to accommodate the different input beam directions. For example, the three colors below could be side-by-side (parallel beams) as illustrated in Figure 10 herein. The three color display can also be generated from a single spatial light modulator chip divided into three sections for convenience of description. In this configuration, the three sections in the area spatial light modulator can be used to generate respectively red, green and blue. The three sections can be registered by synchronization circuits and a phase delay in the electronics of the three color data, thus remove the need for a beam combiner.

After passing through the combiner, the resulting beamlet 54 passes through collimator lens 60 which has the function of collimating the beam and forming a pupil at the scanning surface. Collimated beam 62 is then reflected by wide angle optical scanner 64 which could comprise, for example, a feedback galvanometer scanner mirror that includes synchronization and control unit 66 for synchronizing the motion of the wide angle optical

scanner with the timing of the changes in state of modulators 36-40 as described in more detail below. Synchronization and control unit 66 is coupled to feedback sensor 68, and also to image synchronization signal source 70. Power source 74 is also coupled to synchronization and control unit 66 to drive wide angle optical scanner 64.

Synchronization and control unit 66 receives video synchronization information as follows. Serial video data signal 76 is received and stored in frame memory unit 72. Column data unit 75 receives the stored video data and generates data for modulator drivers 78. It will be appreciated that the video electronics for use with the present invention could be implemented using existing memory modules by one skilled in the art. Just as the bits of the binary word are digitally weighted in a byte, the illumination in the technique of the present invention is weighted for each bit written in the display. As a result, one byte can be read from memory by column data unit 75 and sent to a modulator driver 78 where it is broken into its bits. The bits of one pixel then shift to their appropriate position in the array. This architecture will yield fast and efficient transfer from image memory to the modulator driver and into the modulator elements. More specifically, column data unit 75 takes one complete frame of data from frame memory 72 and reads out a column of data from this frame. The columns comprise one byte which is separated out into eight bits and read into modulator driver 78.

The resulting signal is transmitted to all three modulator drive units 78 along parallel information bus 80 which contains the signals which sequentially drive all RGB modulators 36, 38 and 40.

Light beam 92 is then imaged through projection optic 96 which serves to focus the light onto viewing surface 98, which may comprise, for example, a conventional projection screen. Various kinds of projection optic units can be used; in general, it should maintain high resolution, allow the use of speckle elimination, and satisfy safety considerations.

Referring now to Figs 4A and 4B, there are shown schematic diagrams of light modulators 48 in Figure 3. In Figure 4A, the light modulator is superimposed onto full image 100. However, it should be pointed out that Figure 4A is not drawn to scale, since modulator 48 (in the eight-bit implementation) is only eight modulator elements wide, but image 100 will typically be thousands of pixels wide. Scan direction arrow 101 indicates the direction of the scanning by wide angle optical scanner 64 of modulator 48 across viewing surface 98, which produces image 100. Column data unit 75 (Figure 2) is configured to generate signals to modulators 36, 38 and 40 such that in a given row the modulator element first reaching viewing surface 98 represents the least significant bit (LSB) of the desired gray level of the resulting image for the first upper left most pixel 107 in image 100. In the first row of modulator 48 the LSB is element 104. Similarly, each successive modulator element in the first row of the modulator represents successively more significant bits. Left most pixel 107 represents the most significant bit (MSB) for the gray level of the image in upper left most pixel 107 of image 100. It will be appreciated that for simplicity the present discussion will focus on a single modulator such as red, green or blue modulator 36, 38 and 40. In fact, all three modulators will simultaneously be generating the proper gray level for the respective primary color on image 100 to build up the desired color.

Diagram 108 in Figure 4B is a three-dimensional depiction of the position of the first row of modulator 48 at various points in time. That is, diagram 108 depicts the location of the first row of modulation 48 along space axis 113 at various points along time axis 110. For example, element 104 of modulator 48 is initially located at the upper left pixel 107 of image 100. After eight cycles (or shifts in position of scanner 64) modulator element 104 (which represents the least significant bit of gray level image) is now at the eighth pixel 105 in row one of the image. At this point in time, the most significant bit 106 is at the upper left pixel 107 of image 100. Shaded pixels 115 represent the location of modulator elements not yet scanned in the image.

An understanding of the intensity profile of the beamlets incident upon modulator 48 will serve to explain how the modulator builds up gray level images. Thus, referring now to Figures 4A and 5, there is shown a diagram of the intensity profile of the beamlets applied to various columns of the modulator for the preferred embodiment having eight columns [N = 8] when all of modulator elements are in the "on" state. In Figure 4A this profile is superimposed over the modulator to show the various intensities for each column. For example, each of the modulator elements in the least significant bit column (where element 104 resides), in its "on" state, modulates an intensity of one unit. Each successive column modulates twice the intensity of the previous column until the most significant bit column is reached (where element 106 resides) where 128 units of light intensity are transmitted by the modulator in the "on" state. It is important to note that proceeding down a column of beamlets supplied to modulator 48 from row 1 to M, the illumination intensity is uniform. Proceeding across in the direction of arrow 101 from column 1 to N as shown in Figure 4A, the modulator encodes the gray scale in steps: from full brightness as the most significant bit (equivalent to 128 digital counts shown Figure 5) and successively one-half brightness until it is at the least significant bit of one digital count (the rightmost column in Figure 5).

Consequently, as shown in Figures 4A and 4B, when modulator array 48 enters the image from the left it first writes the least significant bit of the entire first column of the image. (Note that, for simplicity if illustration, diagram 108 shows only the first row in the resulting image.) As deflector 64 shifts the image to the second column, the next significant bit writes in the first column of image 100 while the least significant bit of the second pixel is written in column two. This process continues until the most significant bit of the first column is written, which is the state shown in Figure 4A. At this point, the least significant bit of the eight column is written and the entire modulator array is now actively writing corresponding parts of the image. System 20 continues to write the entire field until the least significant bit of the last column is written, after which the least significant bit portion of the modulator array moves off the image as the more significant bits write the last column of the image. The field has been completed when the most significant bit of the last column has been written in the row at the extreme right of image 100.

Upon completion of the building up of gray levels by a complete scan of image 100, the image information is then updated and the entire process repeated for the next frame of information. In the preferred embodiment the scanning by wide angle optical scanner 64 is accomplished at a 90 Hz frame rate. For example, where N is equal to half of the height of the picture and two scans are required at a frame rate of 90 Hz, the field rate will be 45 Hz. Alternative respective rates could be 120 Hz and 60 Hz. There may be others as yet unknown.

As an alternative to having illumination that decreases in bit-wise steps as shown in Figure 5, an alternative embodiment of the present invention employs modulator 112 with a geometry as shown in Figure 6. In modulator 112 the number of elements across the top of the array correlates to the amount of the brightness. As a result, the illumination (modulator output) is uniform in both the horizontal or row dimension, and in the vertical or column dimension. To digitally weight the uniform illumination, the most significant bit will be represented by the first 128 modulator elements. The successive columns will decrease by a factor of two in the digital count (by decreasing the number of elements) until the last column contains one line of modulator elements and represents the least significant bit. In the first "column" 114 there would actually be 128 columns of elements representing the most significant bit. The next "column" 116 would have half that number, or 64 modulator element columns. The process of cutting the number of modulator elements in half for each succeeding step continues until the last column. In the last column, the least significant bit can be represented by one binary column of elements. Again, the illumination is uniform across the vertical (y dimension) and the horizontal (x dimension) for each column (114, 116 ...) and it is then modulated in both dimensions to form an image.

In the embodiment shown in Figure 6, it will be appreciated that modulator driver 78 will simultaneously drive all 128 modulator elements in the first row of column 114 "on" or "off" as required. Likewise, each succeeding column 116, etc., will also (for any given row) be all "on" or all "off" at any given time. In this way, in the "on" state the light from a single row in column 114 will impinge on a given pixel in image 100. Therefore, that pixel will be exposed to 128 times the brightness as when the first column, having a single modulator element, is "on." Of course, lenses 42, 44, and 46 must be modified to direct all the light from each column (such as 114 and 116) onto a single pixel. The results will then be equivalent to the effect of modulator 48, but having a simplified modulator design due to the uniform intensity at each modulator element.

The foregoing discussion regarding Figure 6 assumed that the light intensity from the beamlets incident upon the modulator is uniform across each row. However, alternatively, the incoming beamlet may have a different intensity profile. For example, the incoming beamlets may be brighter on the left side (where higher intensity is desired), and then decrease linearly or non-linearly, toward the right side. This could permit fewer modulator elements to be used in each column. For example, if the light intensity profile were brighter in column 114 (with respect to the other columns) then fewer than 128 modulator elements would be needed in column 114, thereby reducing the modulator size. Other input light intensity profiles are also possible, such as a Gaussian curve with the highest intensity occurring on the center instead of at the edge. In summary, many different intensity profiles can be used as long as modulator driver 78 controls the modulator so that the total desired intensity level is achieved for each pixel during scanning.

Referring now to Figures 7A and 7B, an alternative modulator intensity profile is shown. This embodiment is useful in applications where fault tolerance and graceful degradation are desired. For example, in color displays used in commercial and military aircraft cockpits, it is critical to maintain the display of useful information to a pilot even in the event of a failure of one of the light sources. In this embodiment, color display system 20 of Figure 2 is modified so that there are two light sources for each color channel and modulators 36, 38 and 40 are modified

to have the intensity profile shown in Figures 7A and 7B. It can be seen that the right most eight columns in the modulator in this embodiment have the same intensity profile as modulator 48 shown in Figure 5. That is, the most significant bit column has an intensity in the "on" state of 128 units and each succeeding column has one-half the intensity at the previously adjacent column. Note that the total intensity of these eight columns together equals 256 units. However, extra column 117 (the left most column of the nine columns shown) is added in Figures 7A and 7B, which has an intensity of 256 units.

In this embodiment, all of the light from one light source is directed to illuminate the first column and the light from the second light source is split to provide beamlets for the other eight channels. Each light source has the same intensity, and this is a level that allows the modulator to achieve 256 light units in its "on" state. That is, when the column 117 is "on," 256 units will be generated from the first column alone and when columns two through nine are "on," 256 total light units of intensity will be generated. For example, 256 light units may correspond to 500 lumens. Thus, by using both light sources, this embodiment allows the production of a 1,000 lumen display, which would be the intensity when all of the columns are in the "on" state; 256 units (500 lumens) from column 117 and 256 units (500 lumens) from columns 2-9.

In operation, if a light source is lost in one of the color channels, this event may be detected, for example, by sensor 68 shown in Figure 2. When this happens, there will be two possibilities. The first, shown in Figure 7A, where the light source in column 117 is lost, the full gray scale is still achievable but at a lower intensity. In order to maintain full dynamic range, the other two color light channels can be turned down to balance the colors. In Figure 7B if the light source illuminating columns 2-9 is lost, this channel will be able to generate one bright pixel of that color (red, for example) using column 1. In this case, the full dynamic range will not be available but at least the color can be achieved, and color symbology maintains integrity.

Referring now to Figure 8, an additional embodiment of the present invention is shown incorporating another modulator 118 having a total of twelve columns. This embodiment gives extremely high brightness and scalability which is useful in many applications such as entertainment theaters and dome simulators where very high brightness is required. That is, columns 5-12 provide eight bits of gray level yielding 256 gray scales, similar to modulator 48. However, modulator 118 has added to it four additional columns of 256 units of intensity each. This may be achieved by stacking additional laser modules as light sources for the additional columns. In this example, where columns 5-12 provide a total of 256 light units, that corresponds to a total 500 lumens of intensity. Each of the additional columns 1-4 adds another 500 lumens to the total intensity. This yields a display with a total intensity of 2,500 lumens. This illustrates how the modular design of the present invention provides easy scalability to achieve very high brightness levels.

Referring now to Figure 9, there are shown a system containing a candidate beam weighing device 124 along with modulator array 122 in accordance with an alternative embodiment of the present invention. The assembly of Figure 9 permits the use of binary modulator array 122 that creates varying intensities in the columns as shown in the intensity profile on modulator 48 (Figures 3A and 4A). Instead each element in modulator 122 transmits the same intensity. This assembly works by utilizing beamsplitter/multiplexer 124 which accepts single

input beam 126 having a single intensity and generates as its output a series of beamlets 128a-128h, each having different intensities. In particular, these intensities match the intensity profile illustrated in Figure 5.

Beamsplitter/multiplexer 124 consists of flat planar member 130 made of a transmissive medium such as optical glass having highly reflective (HR) coating 132 and partially reflective coating 134 on opposing sides. HR coating 132 is 100% reflective and partially reflective coating 134 is 50% reflective. Input beam 126 is a quasi-linear beam which is the size of one column of modulator 48. Input beam 126 first enters the transmissive member 130 through a separate antireflective (AR) coating 136 which has a function of minimizing light loss by passing essentially all of the light. Beam 126 then passes through planar member 130 where it is partially transmitted through partially reflective coating 134 and exits member 130 as beamlet 128a. Approximately one half of this beam, however, is reflected as beam 137 within member 130 which is then 100% reflected by HR coating 132. This causes beam 137 to again reach reflective coating 134 on the opposite side of member 130. As a result, a second beamlet 128b is transmitted out of the beamsplitter/multiplexer 124. Due to the 50% reflectance of coating 134, second beamlet 128b will have approximately one half of the brightness of the first beamlet. As this process continues, each time a beamlet leaves the beamsplitter/multiplexer it has about one half the intensity of the previous beamlet.

Last beamlet 128h will have about 1/128th the brightness of beamlet 128a. The beamlets are then directed through a micro lens array 138 which focuses the beamlets onto the plane of binary modulator array 122. It will be appreciated that binary modulator array 122 will be identical to modulator 48, having M x N rows and columns, and that modulator array will have a uniform transmission for each modulator element when in the "on" state. Since each beamlet 128 has one half of the intensity of the beamlet to the right (from the perspective of Figure 9), the relative intensity of the beamlets passing through binary modulator array 122 will range from intensity units of 1 through 128 as shown in Figure 9. In particular, first beamlet 142 exiting modulator array 122, will have an intensity in the "on" state of one unit. Beamlet 142 corresponds to a beam passing through the least significant bit column of modulator 48, shown Figure 4A. That is, beamlet 142 is a quasi-linear beam which is focused onto the entire least significant bit column of modulator 122. Successive beamlets likewise are each focused onto successive columns of modulator 122 and the highest intensity beamlet 128a is focused onto the most significant bit column of binary modulator array 122 (which corresponds to the most significant bit column of modulator 48).

Thus, by using beam weighing device 124 shown in Figure 9, modulator array 122 will generate as output, for its M x N modulator elements, a light intensity profile of one unit in each modulator element of its least significant bit column and which doubles in each column through the last most significant bit column having 128 units. By employing beam weighing device 124 in the color projection system 20 of Figure 2, the system can operate in essentially an identical manner as described above. However, in this embodiment, a simpler modulator array 122 can be employed which has uniform intensity throughout, and many variances in between.

Referring now to Figure 10, an embodiment of the present invention is shown where the light sources and modulators of Figure 2 are arranged in a more compact configuration. In this configuration the light sources (microlasers 21, 22 and 23), are shown in a parallel configuration, as are light shaping devices 24, 26 and 28.

Likewise, modulators 36, 38 and 40 are also arranged in a parallel configuration. This configuration necessitates a different design for combiner 52 in a manner which will be apparent to one skilled in the art. However, the other elements including collimator lens 60, optical scanner 64, and projection optic 906 are identical to those in Figure 2. Additional elements shown in Figure 2 are omitted from Figure 10 for simplicity of illustration.

The TSDM technique of the present invention can also be easily reconfigured to display many different image formats. Current multimedia platforms are required to display images ranging from NTSC (low resolution) to computer workstation resolution (1280 x 1024) and will soon need to display HDTV (up to 1920 x 1080). Achieving this is difficult with current area modulation devices as they must pick one resolution and alter sampling rates to achieve the other formats. With the TSDM technique of the present invention optical scanner 64 allows tremendous flexibility. The scan rate and angular extent can be altered. An additional small angle scanner could be added to the basic TSDM system to allow scanning in both dimensions. This, along with a change in modulation rate, easily allows multiple image format display. Since this is performed directly, there will not be partial over-sampling or under-sampling which often results in image artifacts.

Figures 3A and 3B illustrate an example of the reduction in modulator element count for high resolution displays achieved by the present invention. For HDTV, where more than two million pixels are needed for the full picture, modulator 48 requires only 8,640 modulator elements, where N=8 and M=1080. This is the maximum number of elements, since M could be one-half or one-quarter of the elements in the total vertical dimension (by utilizing a second scanner), thereby correspondingly decreasing the total number of elements in the modulator. For the 3,000 x 3,000 pixel format (9,000,000 modulator elements) in the full picture, the modulator 48 will only require N=8 and M=3,000 or 24,000 modulator elements at most. As a result of this dramatic reduction in the number of modulator elements, the modulator device will be significantly lower in cost and will have higher yields in production.

This scanning configuration also allows a system designer to include an optical feedback sensor for system status and safety interlocks. Optical feedback sensors 68 could be extended to a linear array allowing closed loop control of the image generation. This would allow the system to detect defects or component failures and adjust accordingly. This would enable fault tolerance and graceful degradation of the system as also described above.

From the foregoing it can be seen that by using a combination of modulator geometry, light shaping, binary weighing of the beamlets, and the unique scan architecture, the present invention can generate a very high resolution image with excellent dynamic range. The generation of gray scales from binary optical modulators greatly reduces the costs and complexity of the optical modulator. The reduction in total elements in the modulating device also will improve the manufacturability and production yields. The complexity, size and cost of the optical scanning system is also reduced as compared with previous display systems which required high speed polygon scanners along with galvanometer deflectors.

An alternative configuration can be used to realize TSDM based images by using multiple columns of an area spatial light modulator (SLM). For example, two columns at each side of the area SLM could be used while the rest of the SLM is inactive. Two light sources with light shaping devices and beam weighing devices could be

employed to generate the two active columns. This configuration could be easily extended to more columns depending upon display system optimization. The advantage to such a system would be to decrease the bandwidth of the modulator elements or to increase the display resolution. Also this configuration could use devices that might normally be rejected if defective in the middle of the SLM. However, since this area is inactive the TSDM system allows the devices to generate high quality images.

Moreover, the present invention achieves the production of digital color by eliminating the imprecision of analog modulation schemes. The extremely high resolution and dynamic range of the present invention can provide "picture window" imagery with an extremely large color gamut. The fixed wavelengths of the microlaser sources used in the preferred embodiments will prevent color shifts, thereby eliminating variation and color rendition from unit to unit. The improvements in image quality resulting from the reproducability of the digital color in precise luminance steps will have broad applications in the fields of simulation, image interpretation, commercial graphic arts, fashion, marketing, interactive multi-media and others.

The combination of microlaser technology with the TSDM scheme provides an all-digital display engine that has the capability to exceed the requirements of future information and video display systems. In particular, the marriage of monochromatic microlaser sources and the TSDM scheme leads to an all-digital optical processing system, producing a color rendition that is not achievable with other display technologies. The TSDM scheme also alleviates the image artifacts, resulting from source amplitude instability and poor beam quality.

An additional embodiment of the TSDM system includes the use of non-active modulator elements in between active modulator elements. As a result, the TSDM system can be realized, for instance, when active and inactive elements are altered dynamically. The dynamic transition from active to inactive elements could be performed mechanically or optically. This would have the advantage of reducing the bandwidth of the spatial light modulator. This could also have the advantage of electronically optimizing the display system.

It will also be appreciated that the present invention may be employed in a number of different types of applications including desktop projections displays, consumer TV's, front and rear projection displays, and head mounted displays such as virtual reality, enhanced reality, trainers and simulators. Applications are also possible in computer graphics, scientific visualization, military displays, next generation digital theater, and high rate, high quality printing/hard copy output devices.

Upon review of the above-detailed invention described it is likely that modifications and improvements will occur to those skilled in the art which are within the scope of the accompanying claims. For example, while a three color system has been described, the advantages of the present invention may also be employed using one or two color channels. Also, this three-color system could easily be extended to four or more colors. This fourth color could include a non-primary orange channel or a non-primary, non-visible near infrared channel. Further, variations in the kinds of light sources and optical elements may be employed. Thus, it will be appreciated that modifications can be made without departing from the true spirit of the invention after studying the specification, drawings and following claims.

WHAT IS CLAIMED IS:

1. An image display system for displaying an image defined by a plurality of pixels, each pixel having pixel data associated therewith, comprising:

a light source means for supplying optical radiation including a plurality of beamlets;

modulation means, responsive to the pixel data, for modulating the plurality of beamlets so that the total intensity of each pixel is represented by a predetermined sequence of said beamlets; and

means for scanning the modulated beamlets in a synchronized manner so that each pixel in the displayed image is formed by sequentially displaying said predetermined sequence of beamlets on said respective pixel.

2. The image display system of Claim 1, wherein said optical radiation has a section having an approximately continuous intensity distribution, and said plurality of beamlets are defined within said section by said modulation means.

3. The image display system of Claim 1, wherein said light source means comprises a plurality of individual light sources, each individual source defining a beamlet.

4. The image display system of Claim 1, wherein said light source means comprises a beam weighing device that defines said plurality of beamlets, each beamlet having a predetermined intensity level.

5. The image display system of Claim 1, further comprising a lens array for receiving said optical radiation, defining said plurality of beamlets, and focusing said plurality of beamlets on said modulation means.

6. The image display system of Claim 1, wherein said modulation means comprises an MxN modulator array having M rows and N columns of modulator elements.

7. The image display system of Claim 6, wherein M is greater than one.

8. The image display system of Claim 6, wherein N equals the number of bits of gray level intensity built up by the scanned beamlets across a given pixel.

9. The image display system of Claim 6, wherein said modulation means comprises a binary modulator.

10. The image display system of Claim 6, wherein said modulation means comprises an analog modulator.

11. The image display system of Claim 6, wherein said modulation means comprises a transmissive modulator.

12. The image display system of Claim 6, wherein said modulation means comprises a reflective modulator.

13. The image display system of Claim 1, wherein the pixel data includes data indicative of the intensity of the pixel, and said modulation means comprises:

a light modulator array having at least one row of modulator elements coupled to receive the plurality of beamlets and modulate each of said beamlets; and

a video processor responsive to said pixel data for generating signals to be supplied to modulate the elements of the light modulator array.

14. The image display system of Claim 13, wherein the beamlets incident upon a row of modulator elements have a varying intensity across said row.

15. The image display system of Claim 14, wherein said light modulator comprises an MxN modulator array having M rows and N columns of modulator elements, where M is greater than one, and the beamlet having the highest intensity of said predetermined intensity levels is modulated in a first column and the beamlet having the lowest intensity is modulated in the Nth column.

16. The image display system of Claim 14, wherein said video processor generates digital signals including a digital row signal for modulating a row, said digital row signal representing a most significant bit of a first pixel in the image, a next significant bit of a second pixel adjacent to the first pixel, a next significant bit of a third pixel adjacent to the second pixel, and continuing in the same pattern through the least significant bit of the Nth pixel in the image.

17. The image display system of Claim 14, wherein:

the plurality of beamlets supplied by said light source have a binary-weighted intensity distribution so that each beamlet has an intensity level that is about one-half of an adjacent beamlet; and

said video processor generates digital signals including a digital row signal for modulating said at least one row, said digital row signal representing a most significant bit of a first pixel of an image, a next significant bit of a second pixel adjacent to the first pixel, a next significant bit of a third pixel adjacent to the second pixel, and continuing in the same pattern through the least significant bit of an Nth pixel of an image.

18. The image display system of Claim 1, wherein said modulation means further comprises:

a light modulator array having at least one row of N modulator elements; and

means for simultaneously modulating adjacent beamlets in said at least one row to provide a modulated beamlet row that includes a most significant bit of a first pixel of an image, a next significant bit of a second pixel adjacent to the first pixel, a next significant bit of a third pixel adjacent to the second pixel, and continuing in the same pattern through the least significant bit of the Nth pixel of an image.

19. The image display system of Claim 18, wherein:

the plurality of beamlets incident upon said at least one row have a binary-weighted intensity distribution so that each beamlet has an intensity level which is about one-half of an adjacent beamlet; and

said modulation means generates digital signals including a digital row signal for modulating said at least one row, said digital row signal representing a most significant bit of a first pixel of an image, a next significant bit of a second pixel adjacent to the first pixel, a next significant bit of a third pixel adjacent to the second pixel and continuing in the same pattern through the least significant bit of the Nth pixel of an image.

20. The image display system of Claim 1, and further comprising a viewing surface for displaying the image scanned by said scanned means.

21.. The image display system of Claim 13, wherein:

the plurality of beamlets comprise a first set of beamlets having a first primary color, a second set of beamlets having a second primary color, and a third set of beamlets having a third primary color;

said modulation means comprises a single spatial light modulator array having a first section within said array for modulating said first set of beamlets, a second section within said array for modulating said second set of beamlets, and a third section within said array for modulating said third set of beamlets, one for each set of primary color beamlets; and

said scanning means comprises means for scanning the first, second, and third sets of beamlets simultaneously; and

said video electronics further comprises means for creating a phase delay between said first, second, and third set of modulated beamlets so that a full color image is generated.

22. The image display system of Claim 1, wherein:

the plurality of beamlets comprises a first set of beamlets having a first primary color, a second set of beamlets having a second primary color, and a third set of beamlets having a third primary color;

said modulation means comprises a first, a second and a third light modulator, one for each set of primary color beamlets; and

said scanning means includes a beam combiner for combining the first, second, and third sets of beamlets, so that a full color image is generated.

23. The image display system of Claim 22, wherein:

the plurality of beamlets further comprises a fourth set of beamlets having a non-primary wavelength;

said modulation means further comprises a fourth light modulator for said fourth set of beamlets; and

said scanning means includes a beam combiner for combining the first, second, third, and fourth sets of beamlets to generate an image.

24. The image display system of Claim 1, wherein:

the plurality of beamlets comprises a first set of beamlets having a first color, and a second set of beamlets having a second color;

said modulation means comprises a first and a second light modulator; and

said scanning means includes a beam combiner for combining the first and second set of beamlets to generate an image.

25. A method of displaying an image comprising the steps of:

(a) generating a plurality of beamlets each having a predetermined light intensity level;

(b) modulating the plurality of beamlets so that the total intensity of each pixel is represented by a predetermined sequence of said beamlets; and

(c) scanning the modulated output in synchronization with a spatial light modulator so that each pixel in the displayed image is formed by sequentially scanning said predetermined sequence of beamlets on said respective pixel.

26. The method of Claim 25, wherein said modulating step comprises modulating said plurality of beamlets with an MxN modulator array having M rows and N columns of modulator elements, wherein M is greater than one.

27. The method of Claim 25, and further comprising the step of displaying a scanned image on a viewing surface.

28. The method of Claim 25, wherein said modulating step further comprises modulating said plurality of beamlets in a light modulator array having at least one row of N modulator elements coupled to receive the plurality of beamlets and modulate each of said beamlets to provide a modulated beamlet row.

29. The method of Claim 28, wherein N equals the number of bits of gray level intensity built up by the scanned beamlets across a given pixel.

30. The method of Claim 28, wherein said modulator row includes N modulator elements, said image includes a pixel row having at least N pixels, and wherein:

said generating step includes producing a row of N beamlets; and

said modulating step further comprises simultaneously modulating adjacent beamlets in said beamlet row to provide a modulated beamlet row that includes a respective modulated beamlet for imaging to each of the N pixels, including a first modulated beamlet for imaging to a first pixel and an Nth modulated beamlet for imaging to an Nth pixel in said pixel row.

31. The method of Claim 30, and wherein said scanning step comprises the steps of scanning to a pixel row in the image that includes at least N+1 pixels in the image:

(a) in a first time interval, imaging a first modulator row to a first pixel group in said pixel row that includes a first pixel through an Nth pixel so that a first modulated beamlet row is imaged to said first pixel group;

(b) in a second time interval, modulating said first modulator row to provide a second modulated beamlet row, and shifting the imaged output from said first modulator row by one pixel to a second pixel group that includes a second pixel through an N+1 pixel, so that said first modulator row is imaged to said second pixel group; and

(c) repeating said steps (a) and (b) for each pixel in the pixel row so that the intensity at each pixel is determined by the beamlets sequentially scanned to said respective pixel during said time intervals.

32. The method of Claim 30, wherein, in said generating step, a beamlet row is generated in which each beamlet in the row has a predetermined light intensity level.

33. The method of Claim 32, wherein said predetermined light intensity level is approximately Gaussian with respect to adjacent beamlets.

34. The method of Claim 32, wherein said predetermined light intensity levels of adjacent beamlets are approximately equal.

35. The method of Claim 32, wherein:

said N beamlets have an intensity that decreases from a highest intensity to a lowest intensity; and

said modulating step further includes simultaneously modulating each of said N beamlets across said at least one row in said modulator array so that the beamlet having the lowest intensity is modulated in a first modulator element and the beamlet having the highest intensity is modulated in the Nth modulator element.

36. The method of Claim 32, wherein:

said N beamlets have a binary-weighted intensity distribution such that each beamlet has an intensity level which is about one-half of the intensity of an adjacent beamlet; and

said modulating step further includes simultaneously modulating each of said N beamlets across said at least one row in said modulator array so that the beamlet having the lowest intensity is modulated in a first modulator element and the beamlet having the highest intensity is modulated in the Nth modulator element.

37. The method of Claim 36, and wherein said scanning step comprises the steps of scanning to a pixel row that includes at least N+1 pixels:

(a) in a first time interval, imaging a first modulator row to a first pixel group in said pixel row that includes a first pixel through an Nth pixel so that a first modulated beamlet row is imaged to said first pixel group;

(b) in a second time interval, modulating said first modulator row to provide a second modulated beamlet row, and shifting the imaged output from said first modulator row by one pixel to a second pixel group that includes a second pixel through an N+1 pixel, so that said first modulator row is imaged to said second pixel group; and

(c) repeating said steps (a) and (b) for each pixel in the pixel row so that the intensity at each pixel is determined by the beamlets sequentially scanned to said respective pixel during said time intervals.

38. The method of Claim 28, wherein:

said generating step generates at least N beamlets having an intensity distribution that decreases from a highest intensity at a first beamlet to a lowest intensity at an Nth beamlet;

said modulating step comprises modulating the beamlets in a light modulator comprising an MxN modulator array having M rows and N columns of modulator elements, wherein M is greater than one;

said generating step includes producing a beamlet array of M rows of N beamlets; and

simultaneously modulating each of said beamlets across each of said rows in said modulator array so that the first beamlet is modulated in a first column and the Nth beamlet is modulated in the Nth column.

39. The method of Claim 38, and further comprising the step of generating said beamlet array so that the intensity distribution of said beamlet row incident upon the modulator is binary-weighted such that each beamlet has an intensity level which is about one-half of the intensity of an adjacent beamlet.

40. The method of Claim 25, wherein:

said generating step comprises producing a first set of beamlets having a first primary color, a second set of beamlets having a second primary color, and a third set of beamlets having a third primary color;

said modulation step comprises modulating said first, second, and third sets, in a first, a second and a third light modulator respectively; and

said display step comprises combining the first, second, and third modulated sets of beamlets so that a full color image is generated.

41. The method of Claim 40, wherein:

said modulation step comprises generating, in a single spatial light modulator array, a first set of beamlets in a first section within said array, a second set of beamlets in a second section within said array, a third set of beamlets in a third section within said array, one for each set of primary color beamlets; and

said display step comprises scanning the first, second, and third sets of beamlets simultaneously; and

said modulation step further comprises creating a phase delay between said first, second, and third set of modulated beamlets so that a full color image is generated.

42. The method of Claim 40, wherein:

said generating step further comprises producing a fourth set of beamlets having a non-primary color;

said modulation step comprises modulating said fourth set in a fourth light modulator; and

said display step includes combining the first, second, third, and fourth modulated sets of beamlets so that an augmented full color image is generated.

43. The method of Claim 25, wherein:

said generating step comprises producing a first set of beamlets having a first color and a second set of beamlets having a second color;

said modulation step comprises modulating said first and second sets in a first and second light modulator respectively; and

said display step includes combining the first and second modulated sets of beamlets to generate an image.

44. A method of displaying a pixel on a viewing surface comprising the steps of:

(a) generating a light beam having a predetermined intensity profile;

(b) modulating the light beam with signals representative of said pixel in a spatial light modulator to generate a timed sequence of predetermined light intensity levels; and

(c) scanning the modulated output in a synchronized manner so that the pixel is displayed by successively scanning said sequence on the respective pixel area in the viewing surface.

45. An image display system for displaying an image defined by a plurality of pixels, each pixel being associated with pixel data indicative of the intensity of the respective pixel, the image display system comprising:

a light source that supplies a plurality of beamlets each having a predetermined light intensity level;

a light modulator responsive to said pixel data, having a plurality of modulator elements situated to receive and modulate said beamlets so that the total intensity of each pixel is represented by a predetermined sequence of modulated beamlets; and

a synchronized scanning system that scans the modulated beamlets in a synchronized manner so that each pixel in the image is formed by sequentially displaying said predetermined sequence of beamlets on said respective pixel.

46. The image display system of Claim 45, and further comprising a video electronics circuit that receives a video signal and converts said video signal to supply pixel data in a predetermined format to said light modulator.

47. The image display system of Claim 45, and further comprising a viewing surface situated to display said image.

48. The image display system of Claim 46, wherein said synchronized scanning system includes a scanner and a sensor coupled to sense the position of the optical element to determine the optical scan speed and position, and thereby to synchronize said video electronics circuit with the scanner.

49. The image display system of Claim 45, wherein said light source comprises a laser.

50. The image display system of Claim 45, wherein said light modulator comprises an MxN modulator array having M rows and N columns of modulator elements.

51. The image display system of Claim 45, wherein M is greater than one.

52. The image display system of Claim 50, wherein N equals the number of bits of gray level intensity built up by the scanned beamlets across a given pixel.

53. The image display system of Claim 50, wherein the light modulator comprises a binary modulator.

54. The image display system of Claim 50, wherein the light modulator comprises an analog modulator.

55. The image display system of Claim 50, wherein the light modulator comprises a transmissive modulator.

56. The image display system of Claim 50, wherein the light modulator comprises a reflective modulator.

57. The image display system of Claim 45, wherein the beamlets incident upon a row of modulator elements have an intensity that varies across said row.

58. The image display system of Claim 57, wherein said light modulator comprises an MxN array having M rows and N columns of modulator elements, wherein M is greater than one, and the beamlet having the highest intensity of said predetermined intensity levels modulated in a first column and the beamlet having the lowest intensity is modulated in the Nth column.

59. The image display system of Claim 57, wherein said predetermined intensity level of said source of light radiation has a binary weighted distribution.

60. The image display system of Claim 46, wherein said video electronics circuit generates digital signals including a digital row signal for modulating a row, said digital row signal representing a most significant bit of a first pixel, a next significant bit of a second pixel adjacent to the first pixel, a next significant bit of a third pixel adjacent to the second pixel, and continuing in the same pattern through the least significant bit.

61. The image display system of Claim 45, wherein:

the plurality of beamlets comprises a first set of beamlets having a first primary color, a second set of beamlets having a second primary color, and a third set of beamlets having a third primary color;

said light modulator comprises a first, a second and a third light modulator, one for each set of primary color beamlets; and

said synchronized scanning system includes a beam combiner for combining the first, second, and third primary beamlets, so that a full color image is generated.

62. The image display system of Claim 61, wherein:

the plurality of beamlets further comprises a fourth set of beamlets having a non-primary color;

said light modulator further comprises a fourth light modulator for said fourth set of beamlets; and

said synchronized scanning system includes a beam combiner for combining the first, second, third, and fourth primary beamlets, so that a full color image is generate.

63. The image display system of Claim 45, where:

the plurality of beamlets comprises a first set of beamlets having a first color and second set of beamlets having a second color;

said light modulator comprises a first and a second light modulator for modulating each set of color beamlets respectively; and

said synchronized scanning system includes a beam combining for combining the first and second beamlets to generate an image.

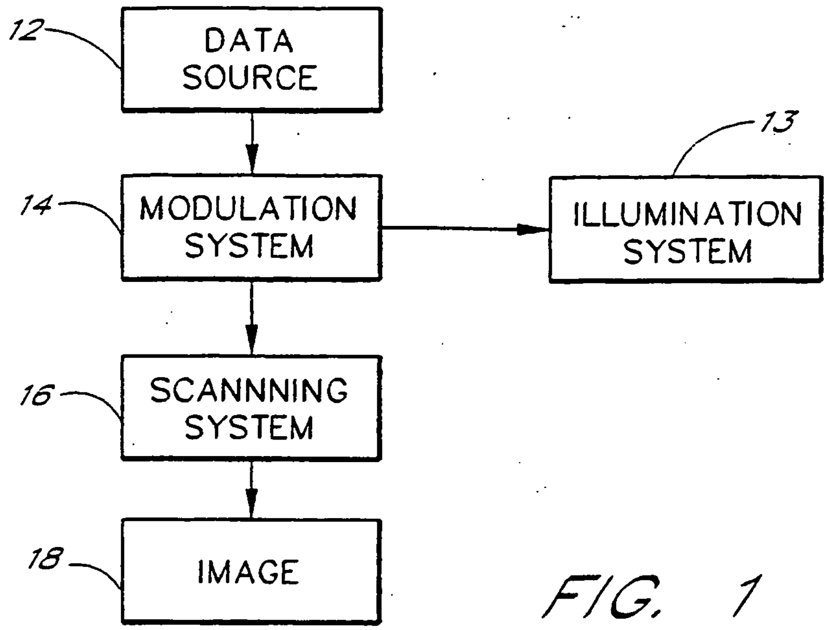

12
DATA SOURCE
14
MODULATION SYSTEM
13
ILLUMINATION SYSTEM
16
SCANNNING SYSTEM
18
IMAGE

FIG. 1

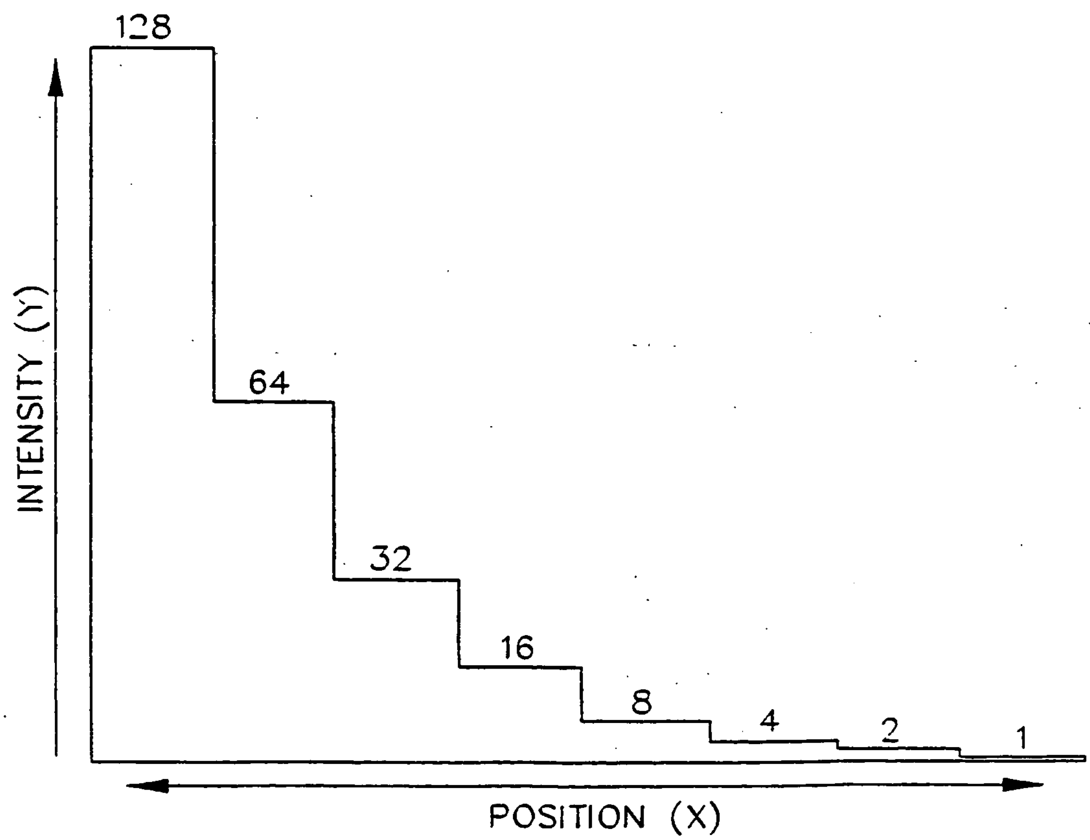

128
64
32
16
8
4
2
1
INTENSITY (Y)
POSITION (X)

FIG. 5

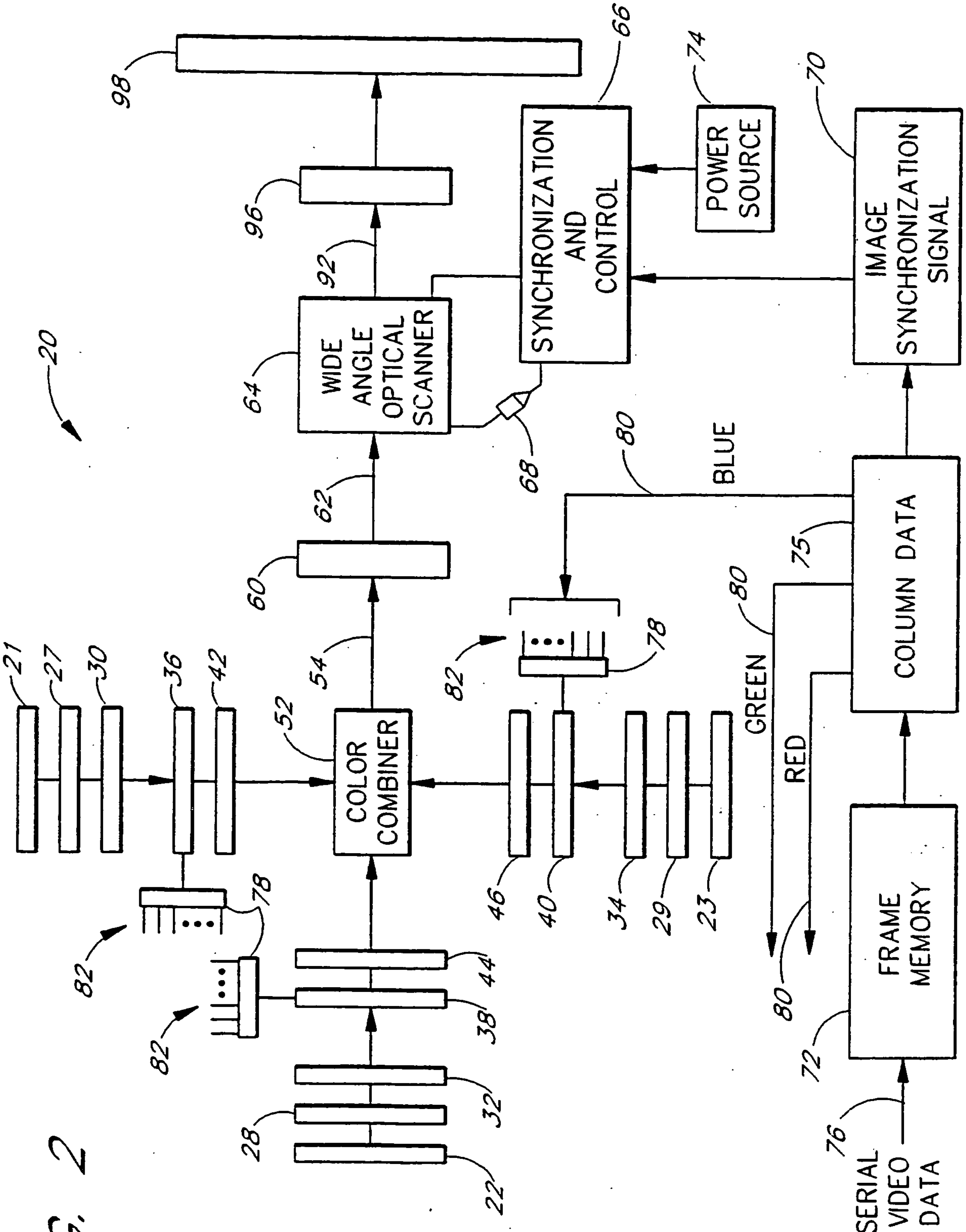

20
98
66
74
70
96
92
64
WIDE ANGLE OPTICAL SCANNER
SYNCHRONIZATION AND CONTROL
POWER SOURCE
IMAGE SYNCHRONIZATION SIGNAL
68
80
BLUE
62
60
COLUMN DATA
75
GREEN
RED
78
82
54
52
COLOR COMBINER
21
27
30
36
42
46
40
34
29
23
44
38
32
28
22
FRAME MEMORY
72
76
SERIAL VIDEO DATA

FIG. 2

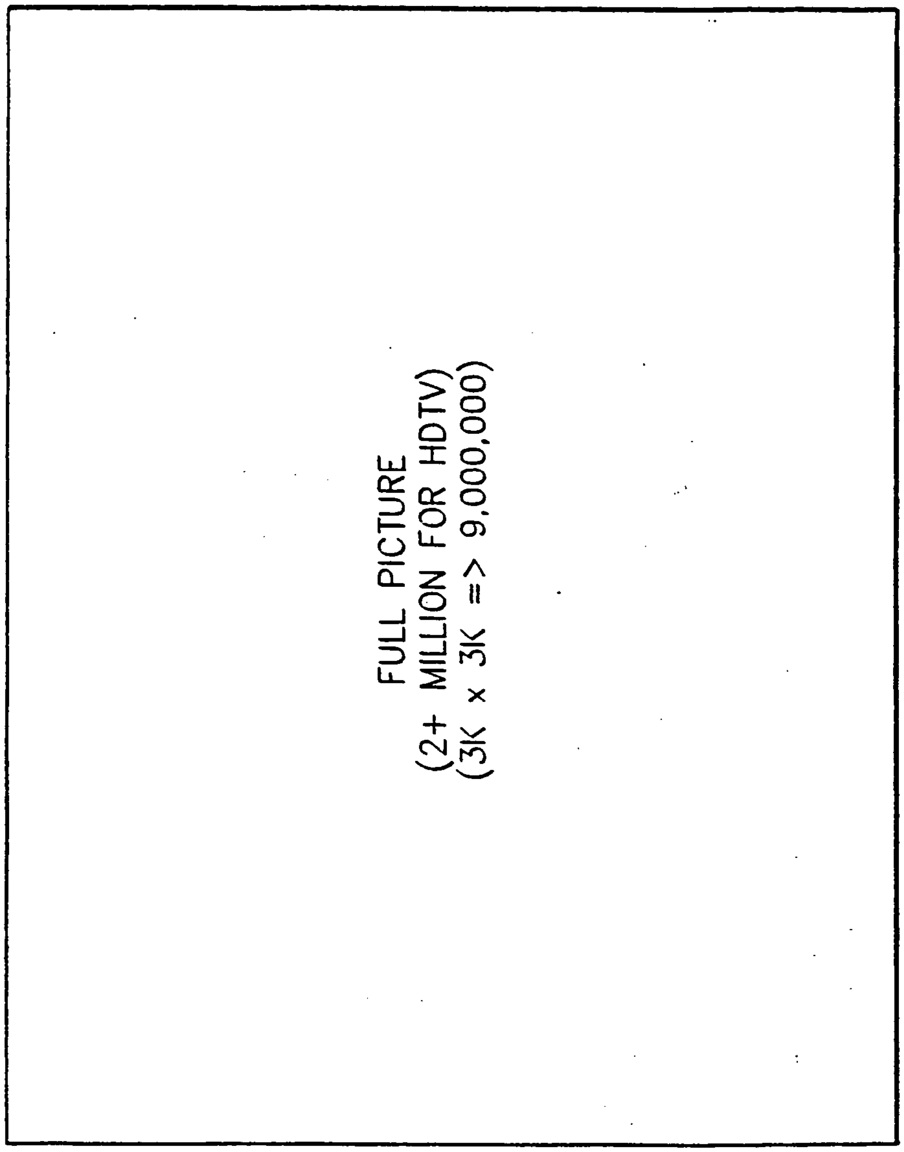

FULL PICTURE
(2+ MILLION FOR HDTV)
(3K x 3K => 9,000,000)

FIG. 3B

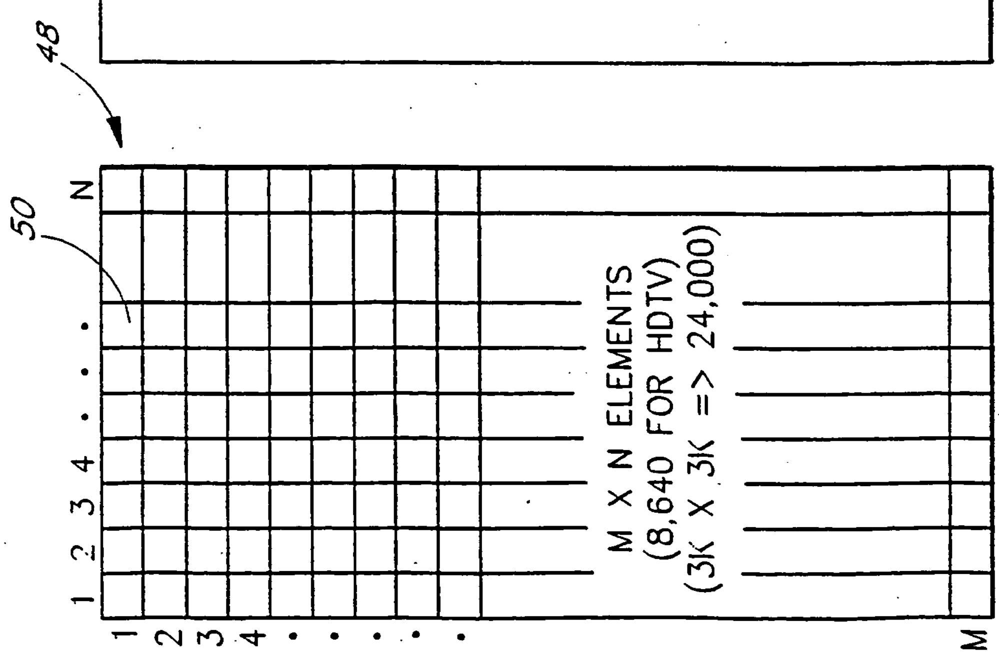

48
50
M X N ELEMENTS
(8,640 FOR HDTV)
(3K X 3K => 24,000)
1
2
3
4
N
M

FIG. 3A

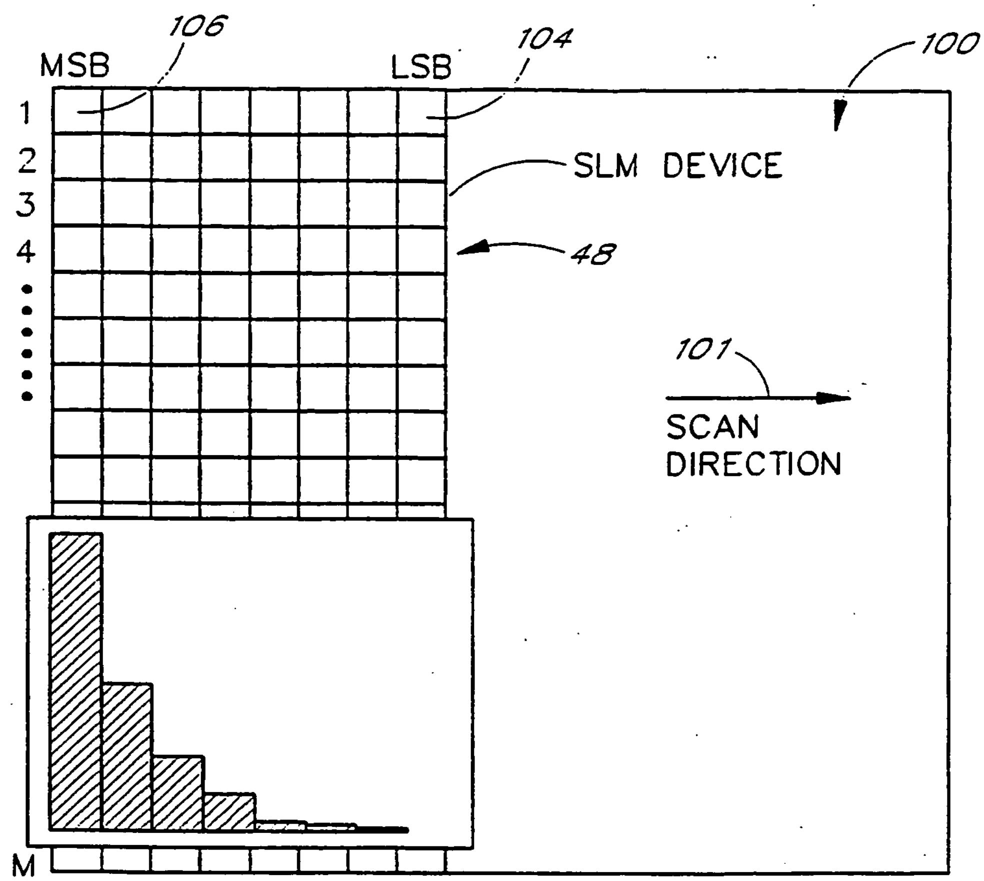

106
104
100
MSB
LSB
1
2
3
4
M
SLM DEVICE
48
101
SCAN
DIRECTION

FIG. 4A

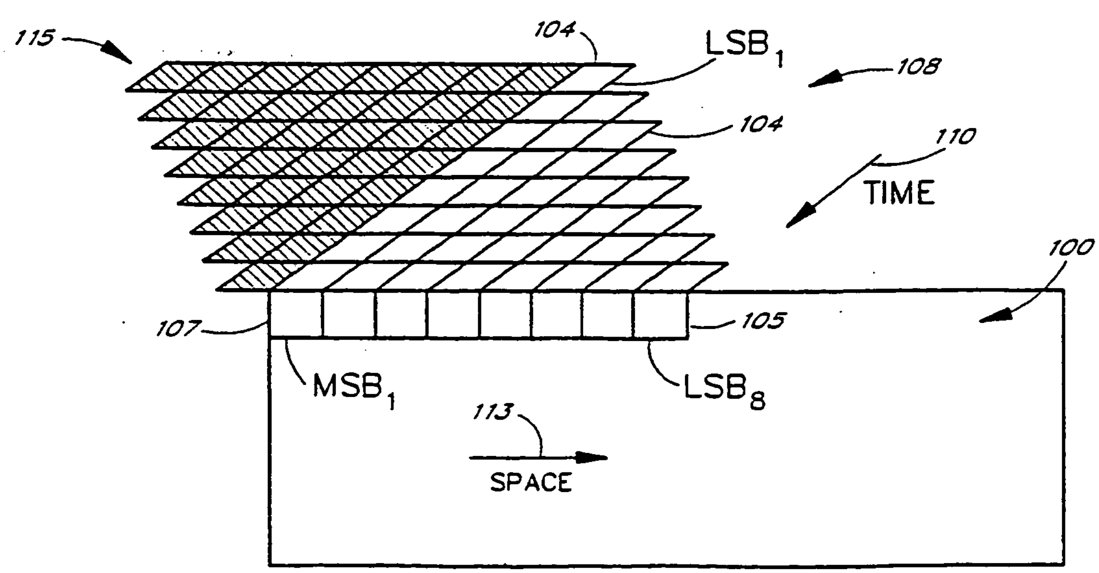
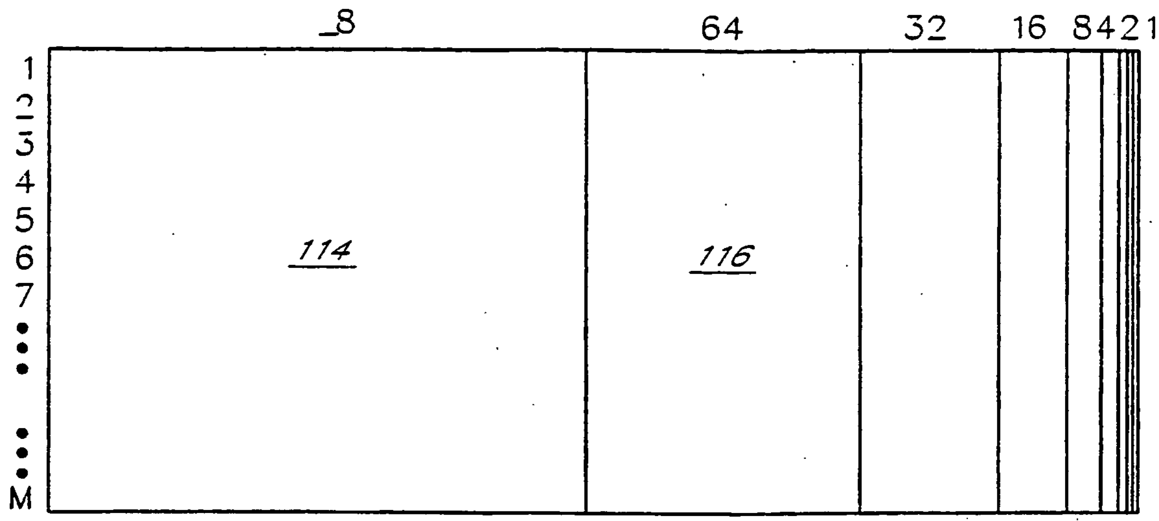
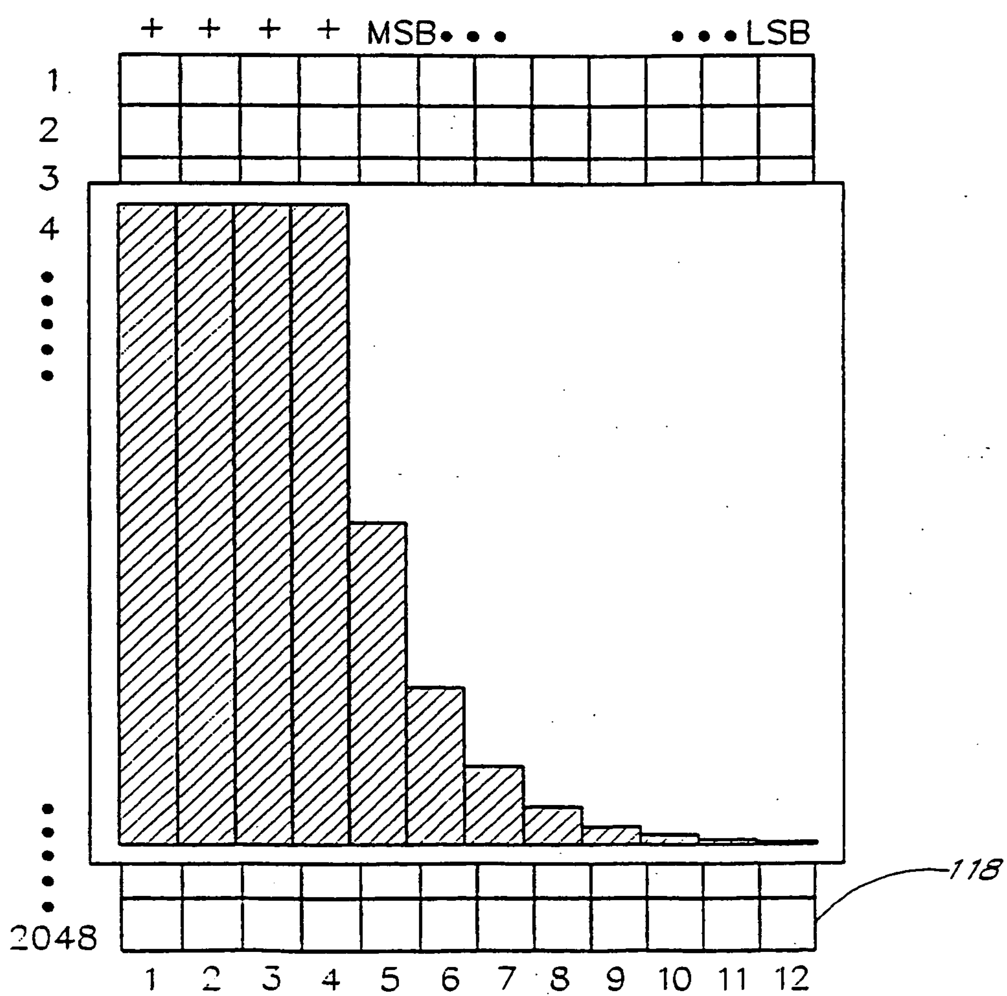

115
104
LSB_1
108
104
110
TIME
100
107
105
MSB_1
LSB_8
113
SPACE

FIG. 4B



8
64
32
16
8
4
2
1
1
2
3
4
5
6
7
M
114
116

FIG. 6



+ + + + MSB • • •
• • • LSB
1
2
3
4
2048
1 2 3 4 5 6 7 8 9 10 11 12
118

FIG. 8

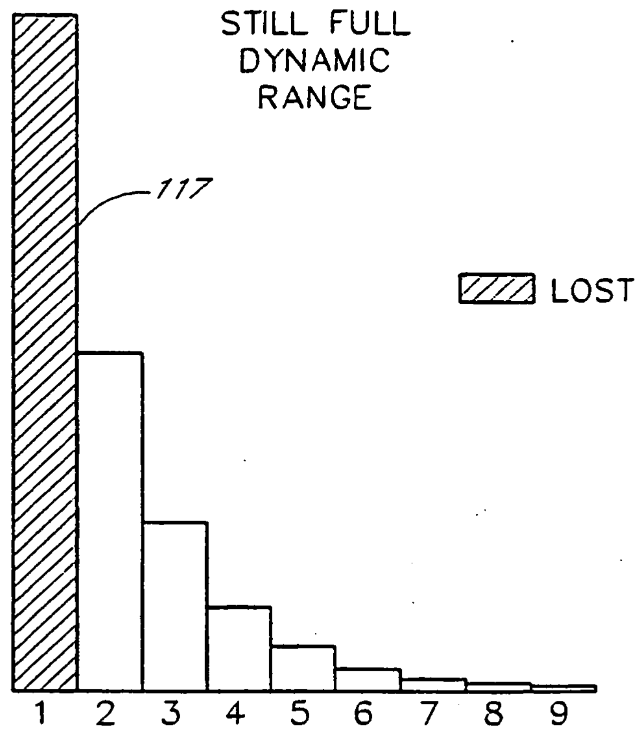

STILL FULL
DYNAMIC
RANGE
117
LOST
1
2
3
4
5
6
7
8
9

FIG. 7A

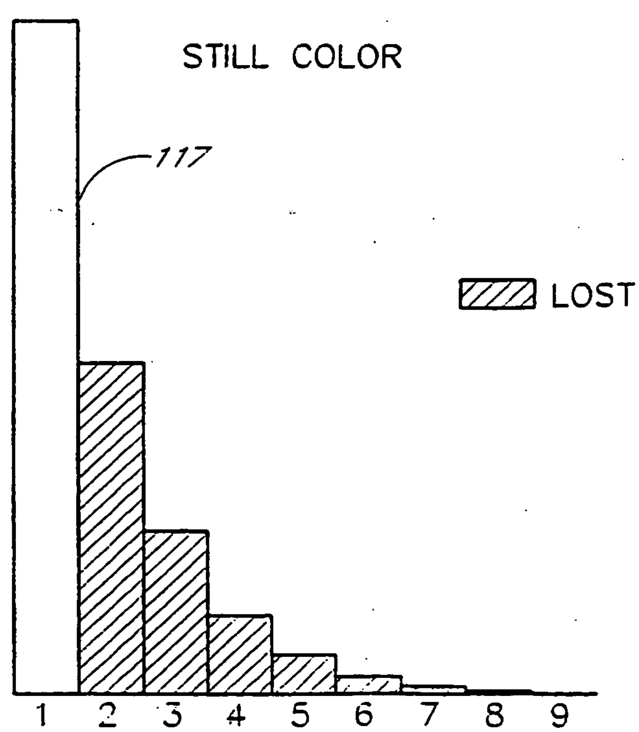

STILL COLOR
117
LOST
1
2
3
4
5
6
7
8
9

FIG. 7B

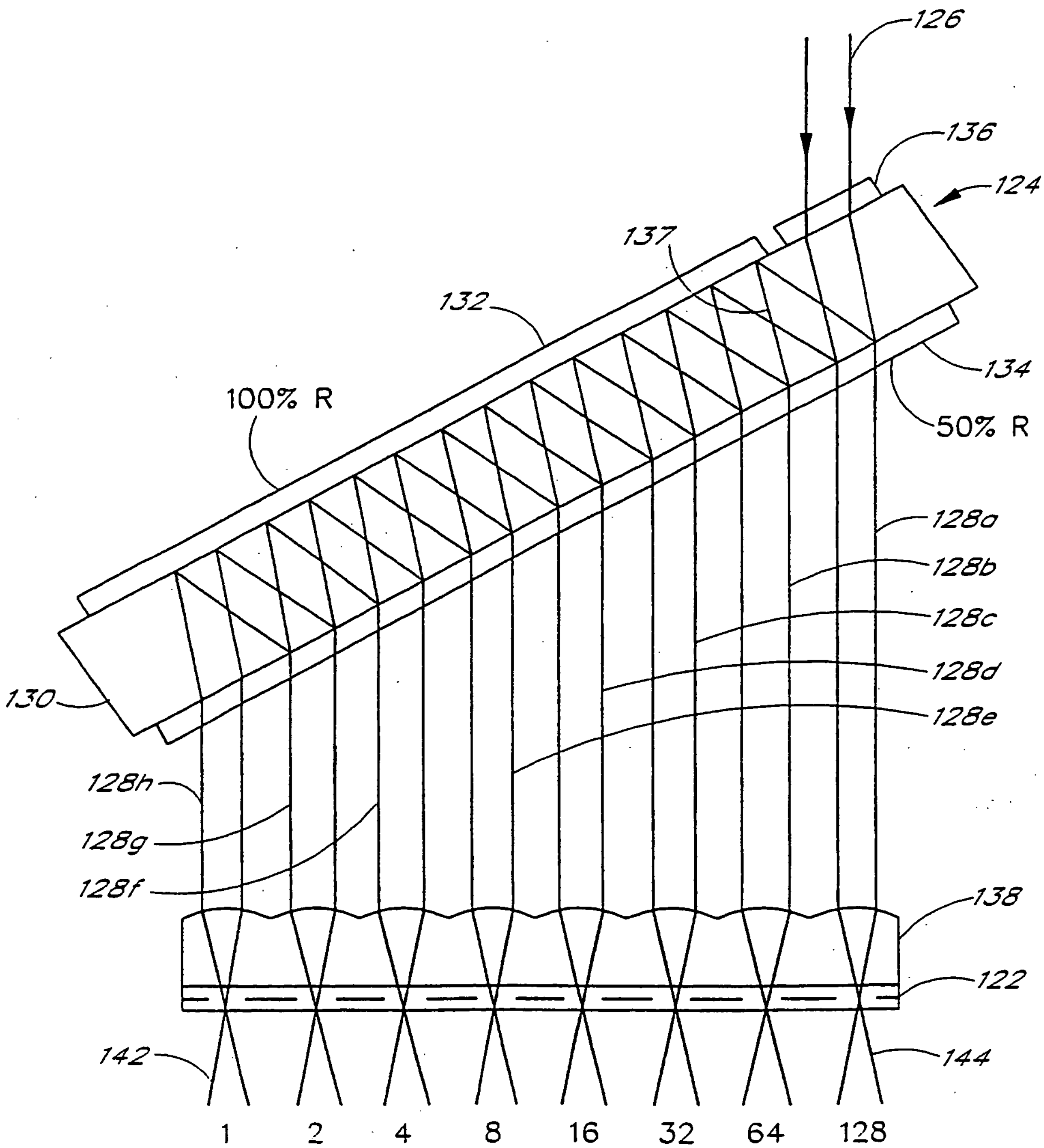

126
136
124
137
132
134
100% R
50% R
128a
128b
128c
128d
128e
130
128h
128g
128f
138
122
142
144
1
2
4
8
16
32
64
128

FIG. 9

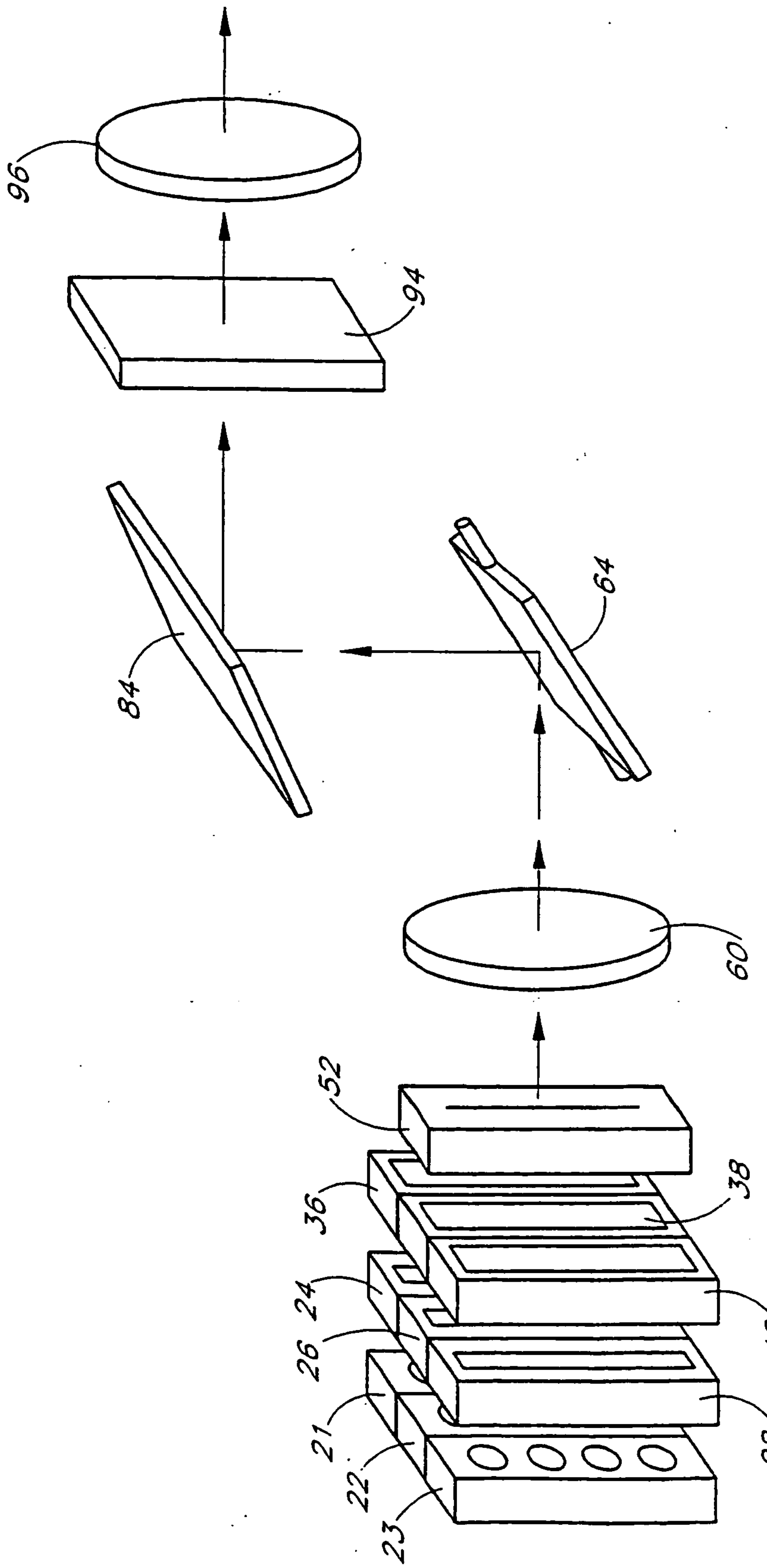


FIG. 10

INTERNATIONAL SEARCH REPORT

Inter   nal Application No
PCT/US 97/19660

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G09G3/00 G09G3/02 H04N5/74 H04N9/31

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G09G H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	-/--	

[X] Further documents are listed in the continuation of box C.

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1

Date of the actual completion of the international search	Date of mailing of the international search report
3 March 1998	12/03/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Corsi, F

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 97/19660

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	see Abstract see page 3, line 8 - line 32 see page 6, line 31 - page 8, line 3 see page 11, line 9 - line 19 see page 16, line 21 - page 17, line 22; figure 1 see page 19, line 32 - page 20, line 27; figure 6 see page 31, line 4 - page 34, line 28; figures 9,10 see page 41, line 12 - page 42, line 16; figure 1A see page 44, line 14 - line 26 ---	9-12,18, 21,32-34
Y	US 4 470 075 A (YOSHIMOTO ET AL.) 4 September 1984	1,3-5, 20,25, 27,40, 41, 44-47, 49,50, 52-57, 59-61
A	see Abstract see column 3, line 26 - column 4, line 46; figures 2,5 see column 5, line 24 - line 63 ---	14,15, 17,19, 28,30, 35,36, 38,39,58
A	US 4 517 608 A (MAEDA ET AL.) 14 May 1985 see Abstract see column 2, line 11 - column 4, line 5; figures 1-5 ---	1,2,8, 29-32
A	EP 0 660 593 A (SONY CO.) 28 June 1995 see Abstract see column 3, line 49 - column 6, line 22; figures 2-4 ---	1,6,7,9, 12,17, 19,26

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1

Inter nal Application No
PCT/US 97/19660

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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A	EP 0 676 740 A (HUGHES AIRCRAFT CO.) 11 October 1995 see Abstract see column 1, line 56 - column 6, line 30; figures 1A-2B ---	22,24, 43,63
A	FR 2 371 107 A (LASER VIDEO INC.) 9 June 1978 see page 1, line 18 - line 36 see page 2, line 22 - page 3, line 7 see page 5, line 18 - page 6, line 15; figure 1 see page 9, line 16 - page 10, line 5; figure 2 see page 19, line 18 - page 20, line 24 -----	42

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 97/19660

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		JP 8046985 A	16-02-96
FR 2371107 A	09-06-78	NONE	

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International Bureau

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08/742,041 1 November 1996 (01.11.96) US

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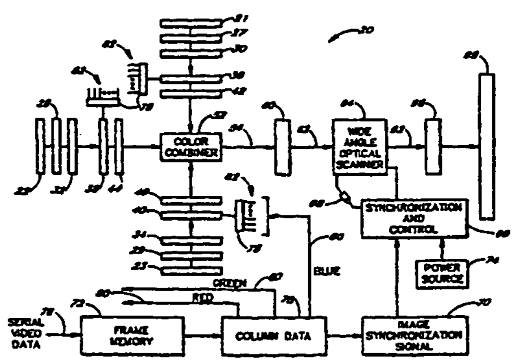
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.
With amended claims

Date of publication of the amended claims: 25 June 1998 (25.06.98)

(54) Title: PROJECTION DISPLAY WITH GRADATION LEVELS OBTAINED BY MODULATION OF BEAMLETS



(57) Abstract

A time synchronized digital modulation (TSDM) image display system (10, 20) that achieves a high level of gray scale resolution while utilizing binary light modulators. By producing color digitally, extremely accurate and consistent color reproduction is achieved. In the preferred embodiment the system includes a light source (21, 22, 23) producing a light beam of optical radiation that is divided into a plurality of beamlets which are modulated in a light modulator (36, 38, 40, 48) having M rows by N columns of modulator elements. Each modulator element (50) has an "on" state and an "off" state that is controllable by a set of image signals. In the "on" state a predetermined beamlet is transmitted by the modulator element, and in the "off" state the beamlet is prevented from being transmitted. When all of the modulator elements are in the "on" state, the intensity of the modulator output varies so that there is a different intensity of light transmitted by each modulator element. The modulated light beam is then scanned across a viewing surface (98). The modulator is synchronised with the scanner (64) so that during each scan a predetermined pattern of "on" and "off" states is present in the modulator, thus projecting a predetermined total intensity level of light onto each pixel of the viewing surface. Due to the speed at which the scanning occurs, a viewer perceives only the total integrated light intensity for each pixel, thereby producing a predetermined gray level (and thus color level) on each image pixel based on the particular pattern of "on" and "off" states of the modulator elements. When spectrally pure lasers are used for the light sources, the TSDM system makes standardizable digital color reproduction possible.

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BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

AMENDED CLAIMS
[received by the International Bureau on 11 May 1998 (11.05.98);
original claims 1-63 replaced by new claims 1-46 (9 pages)]

1. A scanning display system for projecting a visual image on a viewing surface, said image including a plurality of lines each having a plurality of pixels, each pixel having pixel data associated therewith, comprising:

a light source (13) for supplying optical radiation including a plurality of beamlets, each beamlet having a predetermined intensity level and color;

modulation means (14) for modulating said beamlets responsive to the pixel data (76) to generate a row of modulated beamlets, said modulation means modulating said beamlets so that the brightness and color of each pixel in the visual image is represented by a temporal sequence of modulated beamlets; and

means for scanning (16) said image in a series of line scans that include scanning said row of modulated beamlets in synchronization with the modulation means so that each pixel is formed by writing said sequence of modulated beamlets sequentially over said pixel; and

an image projection system (96) for imaging said scanned image to display a visual image.

2. The scanning display system of claim 1 wherein said light source comprises a plurality of individual light sources, each individual source defining a beamlet.

3. The scanning display system of claim 1 wherein said light source comprises a beam weighting device that defines said plurality of beamlets.

4. The scanning display system of claim 1 further comprising a lens array for receiving said optical radiation, defining said plurality of beamlets, and focusing said plurality of beamlets on said modulation means.

5. The scanning display system of claim 1, wherein said plurality of beamlets are monochromatic.

6. The scanning display system of claim 1, wherein:

said plurality of beamlets comprise a first set of beamlets having a first color, a second set of beamlets having a second color, and a third set of beamlets having a third color;

said modulation means further comprises a first set of light modulators for modulating said first set of beamlets to generate a first row of modulated beamlets, a second set of light modulators for modulating said second set of beamlets to generate a second row of modulated beamlets, and a third set of light modulators for modulating said third set of beamlets to generate a third row of modulated beamlets; and

said scanning means further comprises means for scanning said first, second, and third rows of modulated beamlets to generate a multi-color scanned image.

7. The scanning display system of claim 6, wherein:

said modulation means includes a first row of spatial light modulators for modulating said first set of beamlets, a second row of spatial light modulators for modulating said second set of beamlets, and a third row of spatial light modulators for modulating said third set of beamlets; and

said scanning means includes a beam combiner for combining the first, the second, and the third rows of modulated beamlets to generate a combined row of modulated beamlets for scanning each line on the viewing screen.

8. The scanning display system of claim 6 wherein said first color is red, said second color is green, and said third color is blue.

9. The scanning display system of claim 8 and further comprising a fourth set of beamlets having a fourth color, and a fourth set of light modulators for modulating said fourth set of beamlets to generate a fourth row of modulated beamlets.

10. The scanning display system of claim 1 wherein said plurality of beamlets are arranged in a linear configuration, and said modulation means comprises

a row of spatial light modulators situated to receive said linear configuration of beamlets.

11. The scanning display system of claim 10 wherein said light sources supplies optical radiation that includes a section having an approximately continuous intensity distribution, and said plurality of beamlets are defined within said section by said row of spatial light modulators.

12. The scanning display system of claim 10, wherein the beamlets incident upon the row of modulator elements have a varying intensity across said row.

13. The scanning display system of claim 12, wherein the beamlet having the highest intensity is modulated in the first modulator in the modulator row and the beamlet having the lowest intensity is modulated in a last modulator in the modulator row.

14. The scanning display system of claim 12, wherein the number of modulators in a row equals the number of bits of gray level intensity built up by the beamlets scanned across a given pixel.

15. The scanning display system of claim 12, wherein the plurality of beamlets supplied by said light source have a binary-weighted intensity distribution so that each beamlet has an intensity level that is about one-half of an adjacent beamlet.

16. The scanning display system of claim 15, wherein said modulation means further comprises means for simultaneously modulating adjacent beamlets in said row to provide a modulated beamlet row that includes a most significant bit of a first pixel of an image, a next significant bit of a second pixel adjacent to the first pixel, a next significant bit of a third pixel adjacent to the second pixel, and continuing in the same pattern through the least significant bit of the N^{th} pixel of a row.

17. The scanning display system of claim 10, wherein said modulation means comprises a binary modulator.

18. The scanning display system of claim 10, wherein said modulation means comprises an analog modulator.

19. The scanning display system of claim 10, wherein said modulation means comprises a transmissive modulator.

20. The scanning display system of claim 10, wherein said modulation means comprises a reflective modulator.

21. The scanning display system of claim 10, wherein said modulation means comprises a video processor responsive to said pixel data for generating signals to be supplied to modulate the elements of the light modulator array.

22. The scanning display system of claim 21, wherein said scanning means includes a sensor coupled to determine the optical scan speed and position of the scanned beam, and thereby to synchronize said video electronics circuit with the scanning means.

23. The scanning display system of claim 10, wherein said modulation means comprises an MxN modulator array having M rows and N columns of modulator elements.

24. The scanning display system of claim 23, wherein the beamlets have a constant intensity in each of said columns.

25. The scanning display system of claim 24, wherein the beamlets incident upon the row of modulator elements have a varying intensity across each row.

26. The scanning display system of claim 10, wherein:

the plurality of beamlets comprise a first set of beamlets having a first color, a second set of beamlets having a second color, and a third set of beamlets having a third color;

said row of spatial light modulators comprises a first section for modulating said first set of beamlets, a second section for modulating said second set of beamlets, and a third section for modulating said third set of beamlets; and

said modulation means further provides a phase delay between said first, second, and third set of modulated beamlets so that a full color image is generated.

27. The scanning display system of claim 26 wherein said first color is red, said second color is green, and said third color is blue.

28. The scanning display system of claim 26, wherein:

the plurality of beamlets further comprises a fourth set of beamlets having a non-primary wavelength; and

said row of spatial light modulators further comprises a fourth section for modulating said fourth set of beamlets.

29. The scanning display system of claim 1 wherein:

said plurality of beamlets are arranged in a linear configuration having a binary-weighted intensity distribution wherein each beamlet has an intensity level that is about one-half of an adjacent beamlet;

said modulation means comprises a row of binary spatial light modulators situated to receive said linear configuration of beamlets and to modulate them between a first binary state and a second binary state.

30. The scanning display system of claim 29, wherein said modulation means further comprises means for simultaneously modulating adjacent beamlets in said row to provide a modulated beamlet row that includes a most significant bit of a first pixel of an image, a next significant bit of a second pixel adjacent to the first pixel, a next significant bit of a third pixel adjacent to the second pixel, and continuing in the same pattern through the least significant bit of the N^{th} pixel of a row.

31. A method of scanning a visual image on a viewing surface, said image being defined by a plurality of lines each having a plurality of pixels, each pixel having pixel data associated therewith, comprising the steps of:

a) generating a plurality of beamlets having a predetermined light intensity and color;

b) modulating the plurality of beamlets to generate a row of modulated beamlets, so that the brightness and color of each pixel in the visual image is represented by a temporal sequence of modulated beamlets; and

c) scanning the image in a series of line scans that include scanning the row of modulated beamlets in synchronization with said modulation step so that each pixel is formed by scanning said sequence of modulated beamlets sequentially over said pixel; and

d) projecting said scanned image on the viewing screen to display a visual image.

32. The method of claim 31 wherein:

said generating step comprises producing a first set of beamlets having a first color, a second set of beamlets having a second color, and a third set of beamlets having a third color;

said modulation step comprises modulating said first, second, and third beamlet sets in a first, second, and third light modulator respectively to generate a first row, a second row, and a third row of modulated beamlets; and

said scanning step includes scanning the first, second, and third modulated sets of beamlets to generate a multi-color scanned image.

33. The method of claim 31, wherein said first color is red, said second color is green, and said third color is blue, and further comprising the steps of:

combining said first, second, and third modulated sets of beamlets to generate a combined row; and

scanning said combined row so that a full color image is generated.

34. The method of claim 33, wherein:

said generating step further comprises producing a fourth set of beamlets having a non-primary color;

said modulation step comprises modulating said fourth set in a fourth light modulator; and

said combining step includes combining the fourth modulated set of beamlets with the first, second, and third modulated sets of beamlets to generate said combined row; and

scanning said combined row so that an augmented full color image is generated.

35. The method of claim 33, wherein:

said first color is red, said second color is green, and said third color is blue;

said modulation step further comprises applying said first, second and third sets of beamlets to a row of spatial light modulators, and modulating said first set in a first section of said row, modulating said second set in a second section of said row, and modulating said third set in a third section of said row;

said modulation step further comprises creating a phase delay between said first, second, and third set of modulated beamlets; and

scanning said modulated row over a plurality of lines so that a full color visual image is displayed.

36. The method of claim 31, wherein:

said generating step includes generating N beamlets in a linear configuration; and

said modulating step further comprises applying said linear configuration of beamlets to a row of N spatial light modulators.

37. The method of claim 36, wherein:

said modulating step further comprises simultaneously modulating adjacent beamlets in said modulator row to provide a modulated beamlet row of N modulated beamlets for imaging respectively to N pixels in a scan line.

38. The method of claim 37, and wherein said scanning step comprises the step of scanning a line that includes at least N+1 pixels, including the steps of:

(a) in a first time interval, writing a first modulated set of N modulated beamlets to a first group of N pixels in said line;

(b) in a second time interval, scanning to the next pixel in the line and writing a second modulated set of N modulated beamlets to a second group of N pixels that includes a second pixel through an N+1 pixel; and

(c) repeating said steps (a) and (b) for each pixel in the line so that the intensity at each pixel is determined by the beamlets scanned sequentially on each pixel.

39. The method of claim 36, wherein said generating step comprises generating a linear configuration of N beamlets having an approximately continuous, Gaussian intensity distribution.

40. The method of claim 36, wherein said generating step comprises generating a linear configuration of N beamlets in which the light intensities of adjacent beamlets are approximately equal.

41. The method of claim 36, wherein:

said generating step comprises generating a linear configuration of N beamlets in which said N beamlets have an intensity that decreases from a highest intensity to a lowest intensity.

42. The method of claim 36, wherein:

said generating step comprises generating a linear configuration of N beamlets in which said N beamlets have a binary-weighted intensity distribution such that each beamlet has an intensity level which is about one-half of the intensity of an adjacent beamlet; and

said modulating step comprises binary modulating each of said modulators to a first binary state or a second binary state.

43. The method of claim 42, and further comprising the steps of:

(a) in a first time interval, binary modulating said beamlets and writing the resulting modulated set of N modulated beamlets to a first group of N pixels in said line;

(b) in a second time interval, binary modulating said beamlets, scanning to the next pixel in the line and writing a second modulated set of N modulated beamlets to a second group of N pixels that includes a second pixel through an N+1 pixel; and

(c) repeating said steps (a) and (b) for each pixel in the line so that the intensity at each pixel is determined by the beamlets scanned sequentially on each pixel.

44. The method of claim 31, wherein:

said generating step includes producing a beamlet array of M rows of N beamlets; and

said modulating step comprises modulating said beamlets in an array of spatial light modulators having M rows and N columns of modulator elements.

45. The method of claim 44 and further comprising the step of

simultaneously modulating each of said beamlets across each of said rows in said modulator array.

46. The method of claim 44 wherein:

said generating step comprises generating a linear configuration of N beamlets in which said N beamlets have a binary-weighted intensity distribution such that each beamlet has an intensity level which is about one-half of the intensity of an adjacent beamlet; and

said modulating step comprises binary modulating each of said modulators to a first binary state or a second binary state.

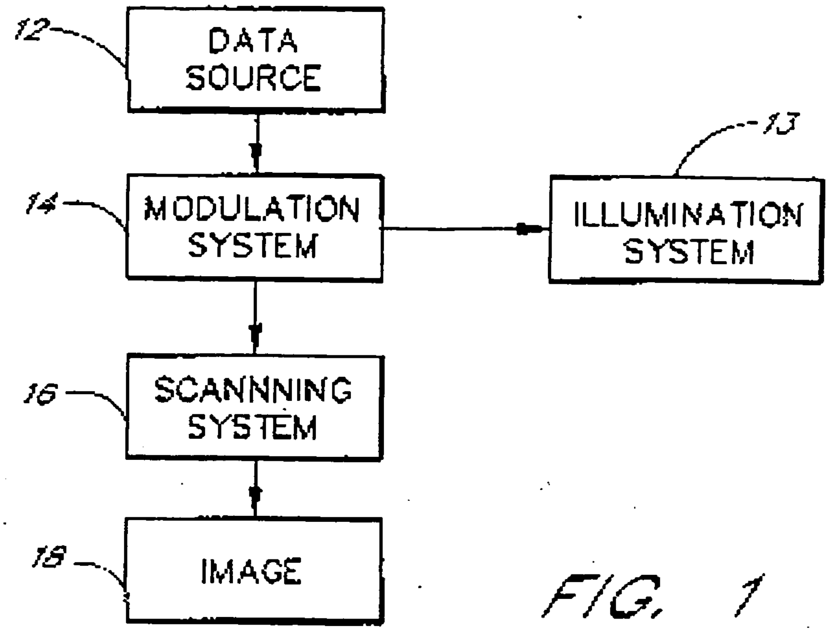

12
DATA SOURCE
14
MODULATION SYSTEM
13
ILLUMINATION SYSTEM
16
SCANNNING SYSTEM
18
IMAGE

FIG. 1

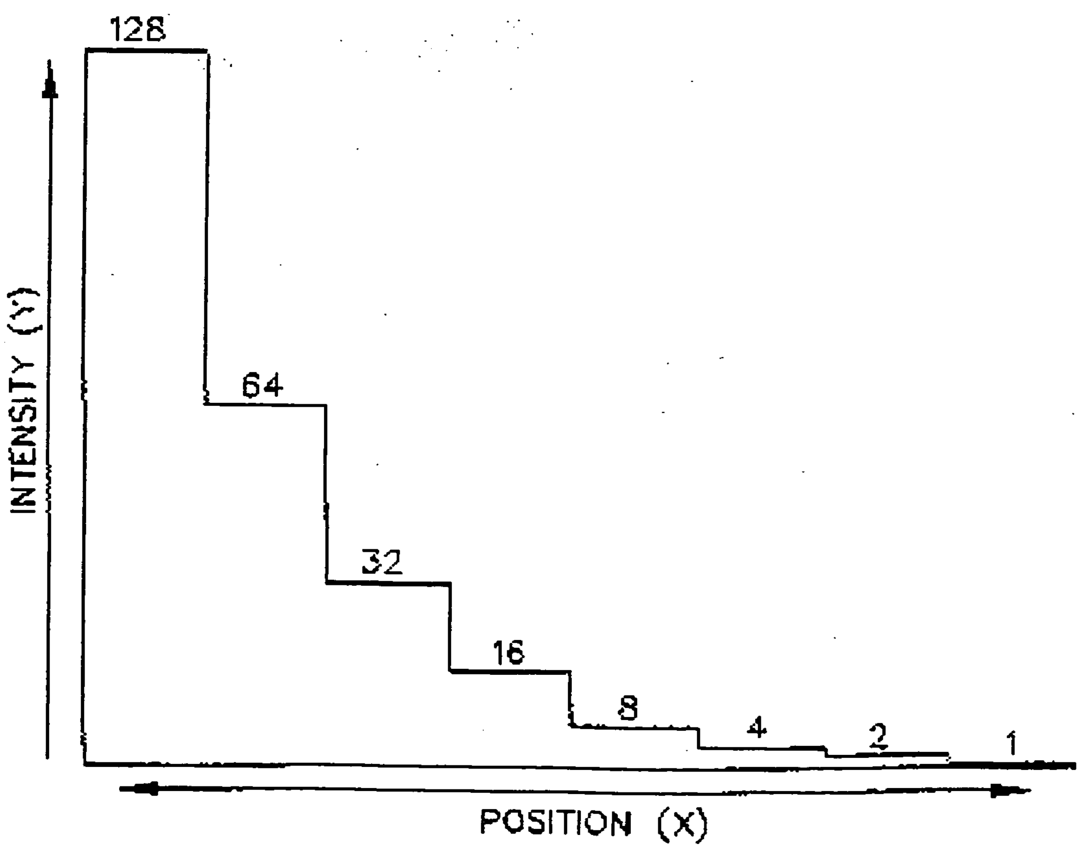
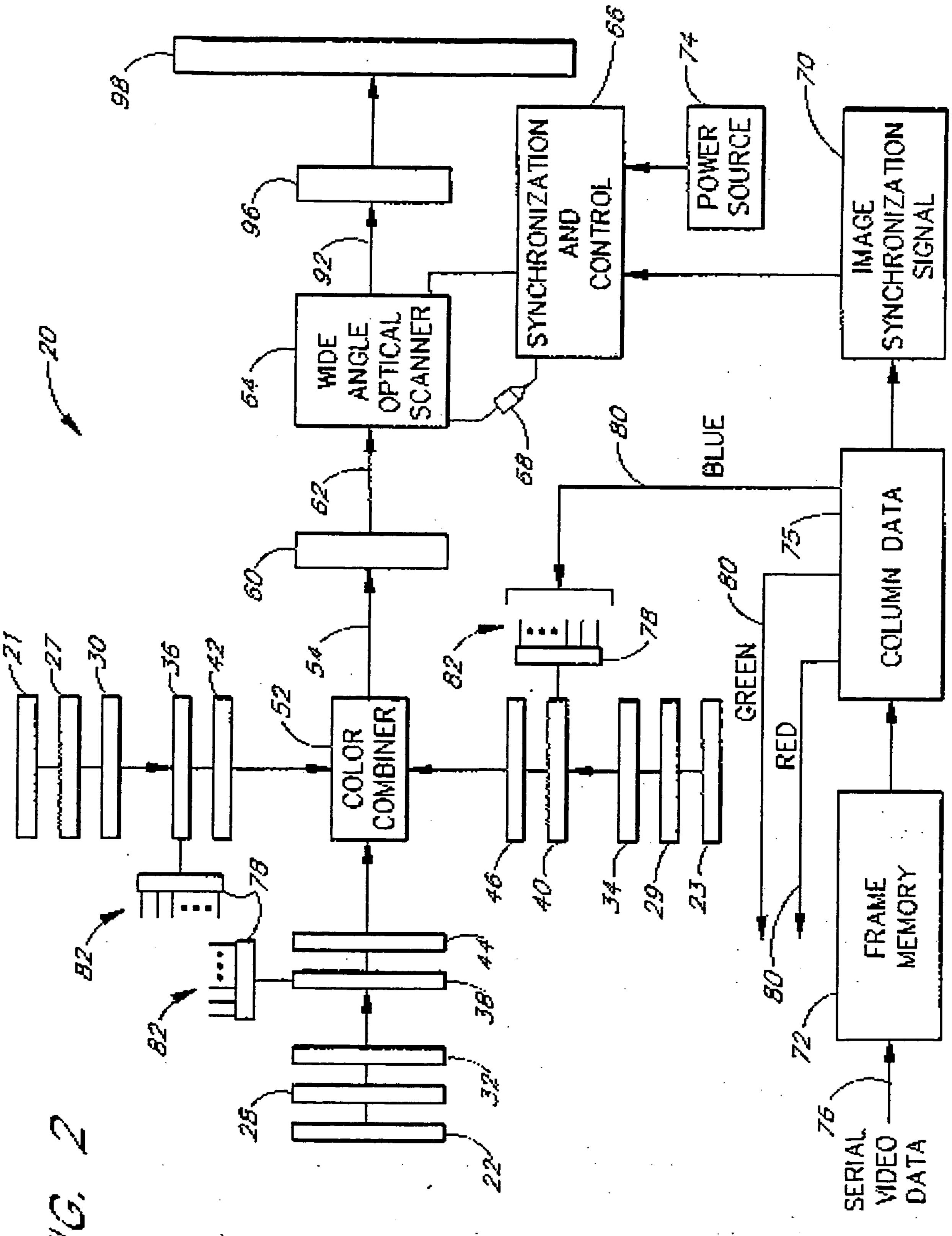

128
64
32
16
8
4
2
1
INTENSITY (Y)
POSITION (X)

FIG. 5

2/8



SYNCHRONIZATION AND CONTROL
POWER SOURCE
IMAGE SYNCHRONIZATION SIGNAL
WIDE ANGLE OPTICAL SCANNER
COLOR COMBINER
COLUMN DATA
FRAME MEMORY
SERIAL VIDEO DATA
BLUE
GREEN
RED
20
21
22
23
26
27
29
30
32
34
36
38
40
42
44
46
52
54
60
62
64
66
68
70
72
74
75
76
78
80
82
92
96
98

FIG. 2

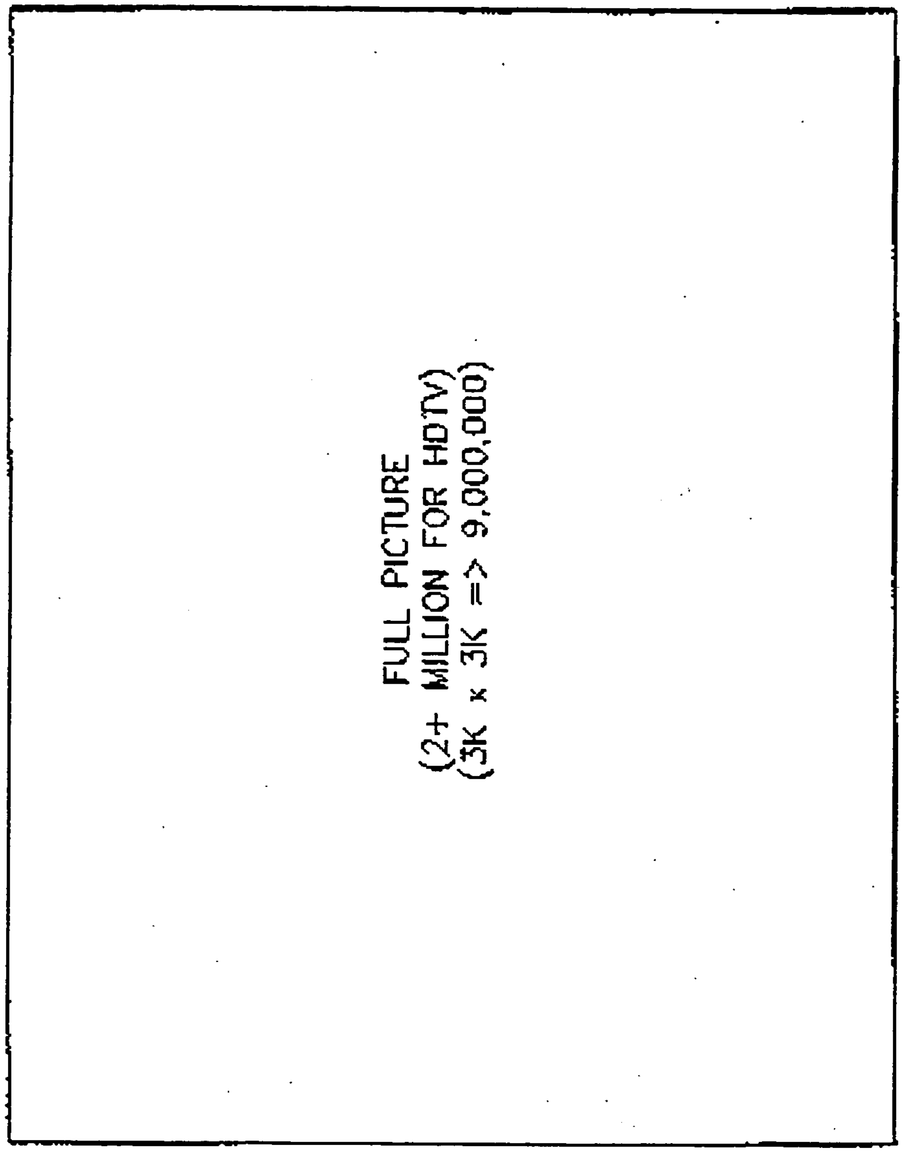

FULL PICTURE
(2+ MILLION FOR HDTV)
(3K x 3K => 9,000,000)

FIG. 3B

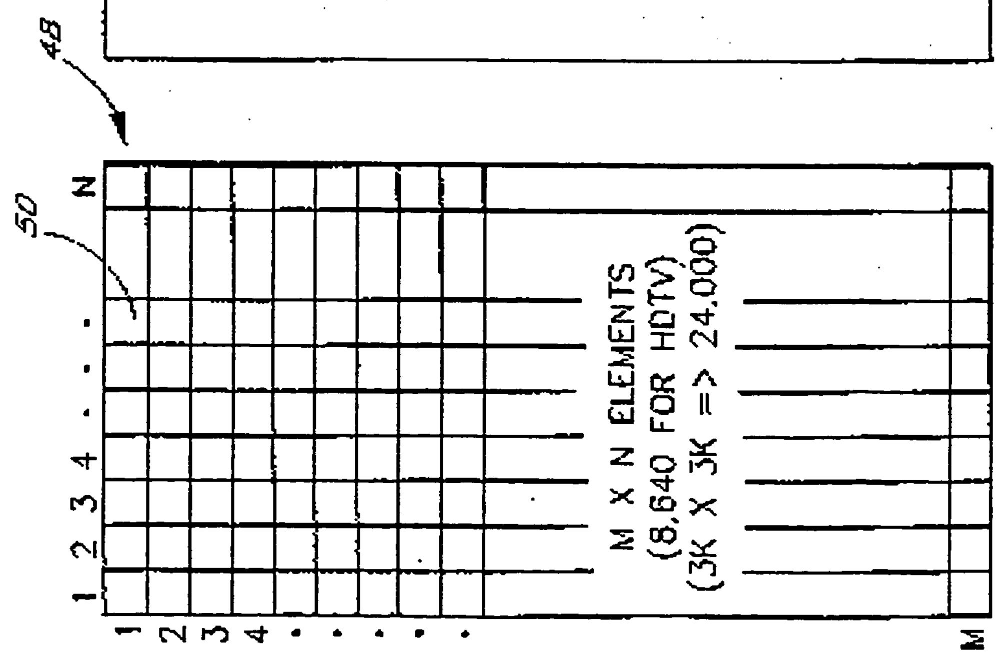
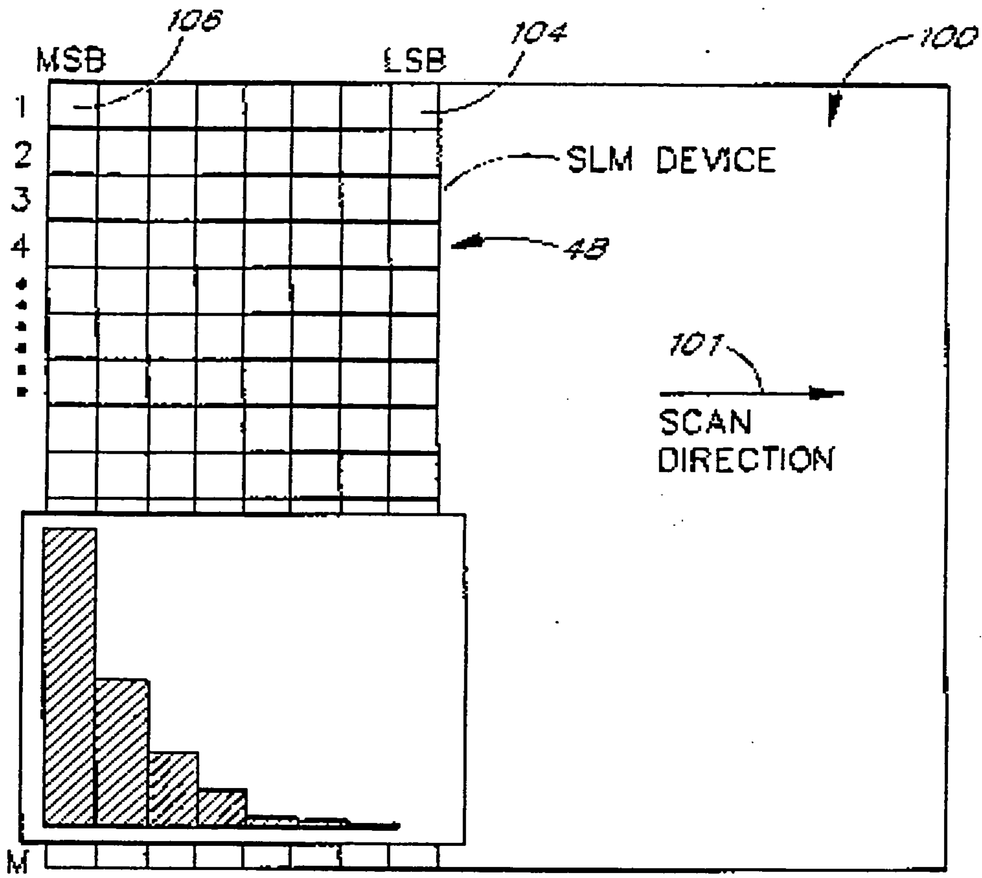
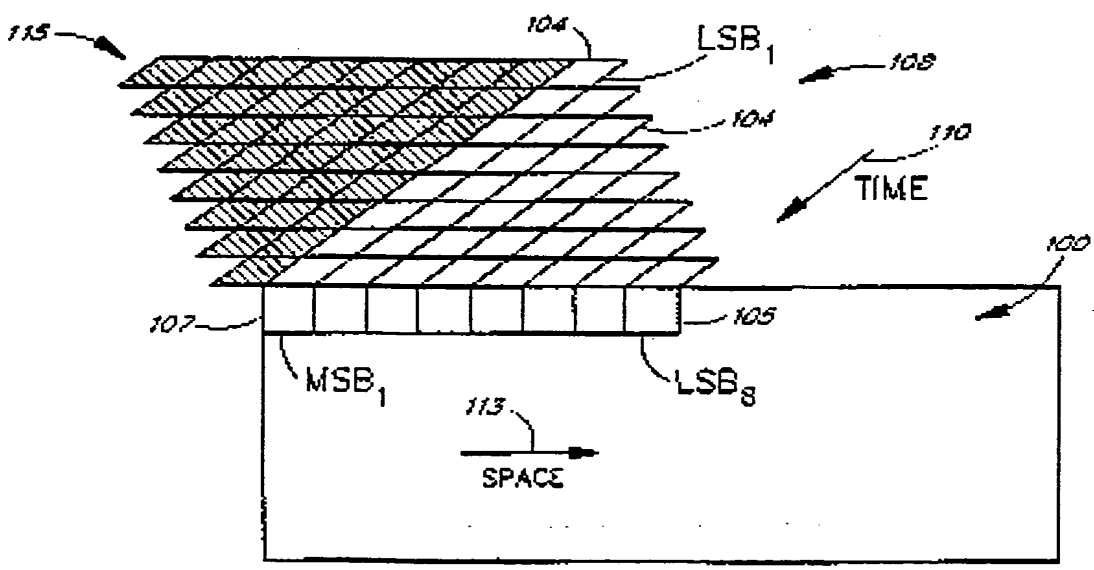

48
50
1
2
3
4
N
M
M X N ELEMENTS
(8,640 FOR HDTV)
(3K X 3K => 24,000)

FIG. 3A



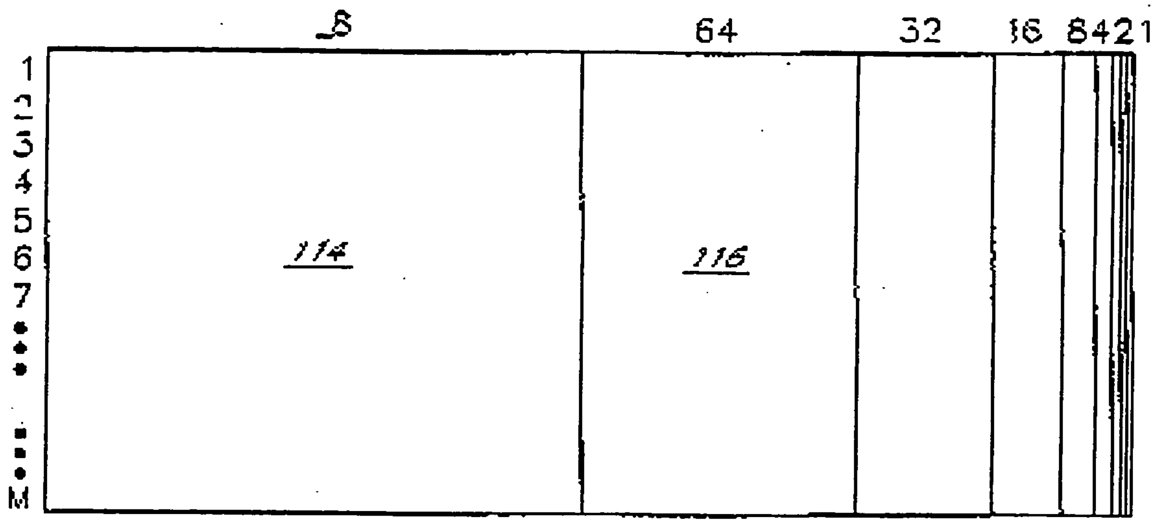
106
104
100
MSB
LSB
1
2
3
4
M
SLM DEVICE
4B
101
SCAN
DIRECTION

FIG. 4A



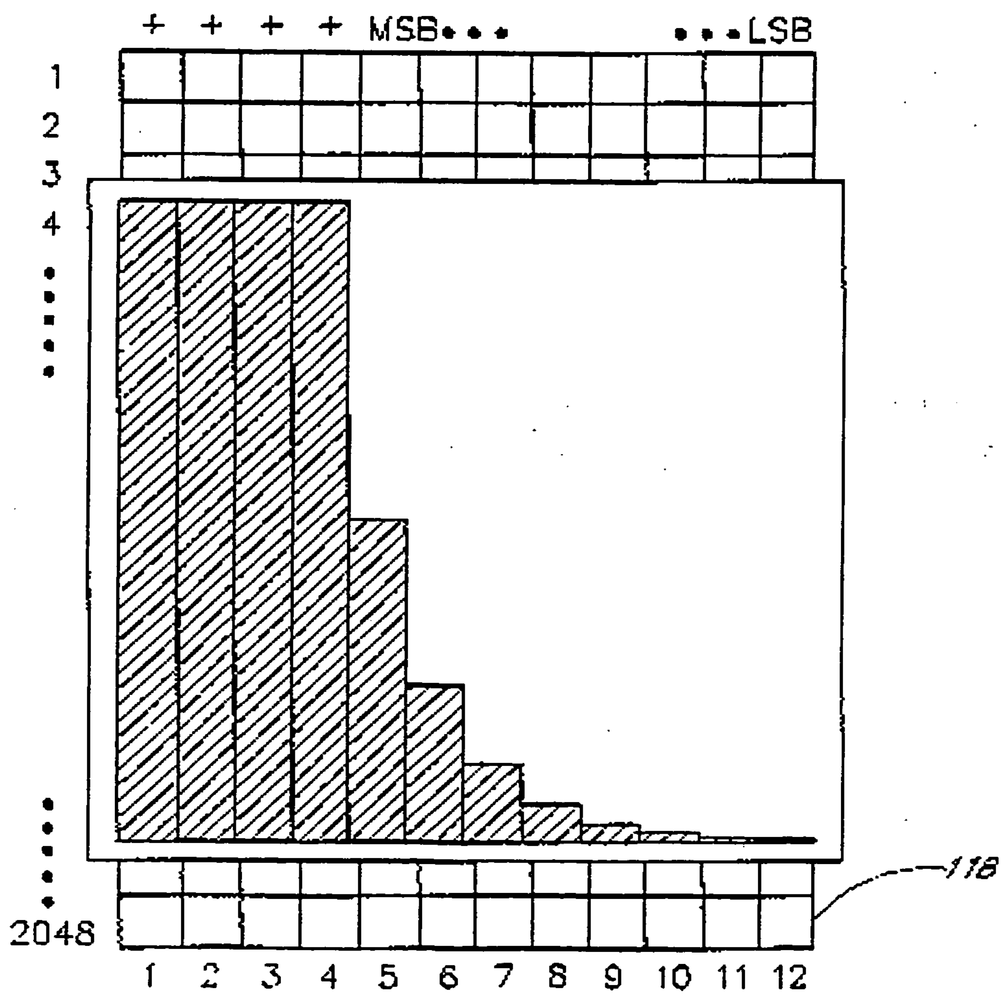
115
104
LSB$_1$
108
104
110
TIME
100
107
105
MSB$_1$
LSB$_8$
113
SPACE

FIG. 4B



128
64
32
16
8
4
2
1
1
2
3
4
5
6
7
M
114
116

FIG. 6



+ + + + MSB • • • • • • LSB
1
2
3
4
2048
1 2 3 4 5 6 7 8 9 10 11 12
118

FIG. 8

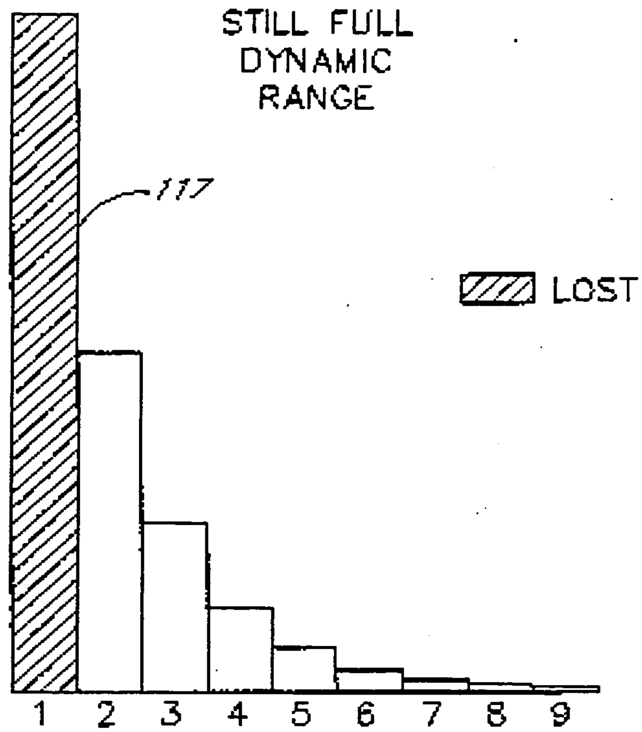

STILL FULL DYNAMIC RANGE
117
LOST
1
2
3
4
5
6
7
8
9

FIG. 7A

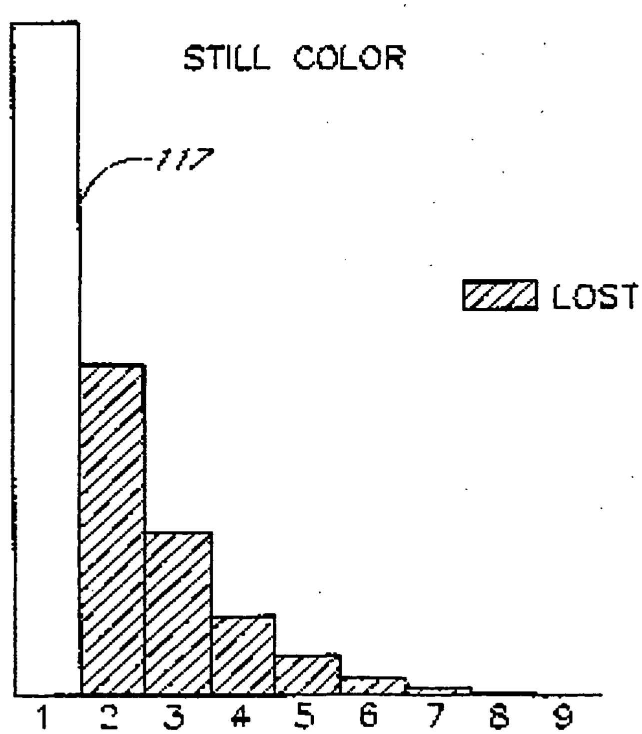

STILL COLOR
117
LOST
1
2
3
4
5
6
7
8
9

FIG. 7B

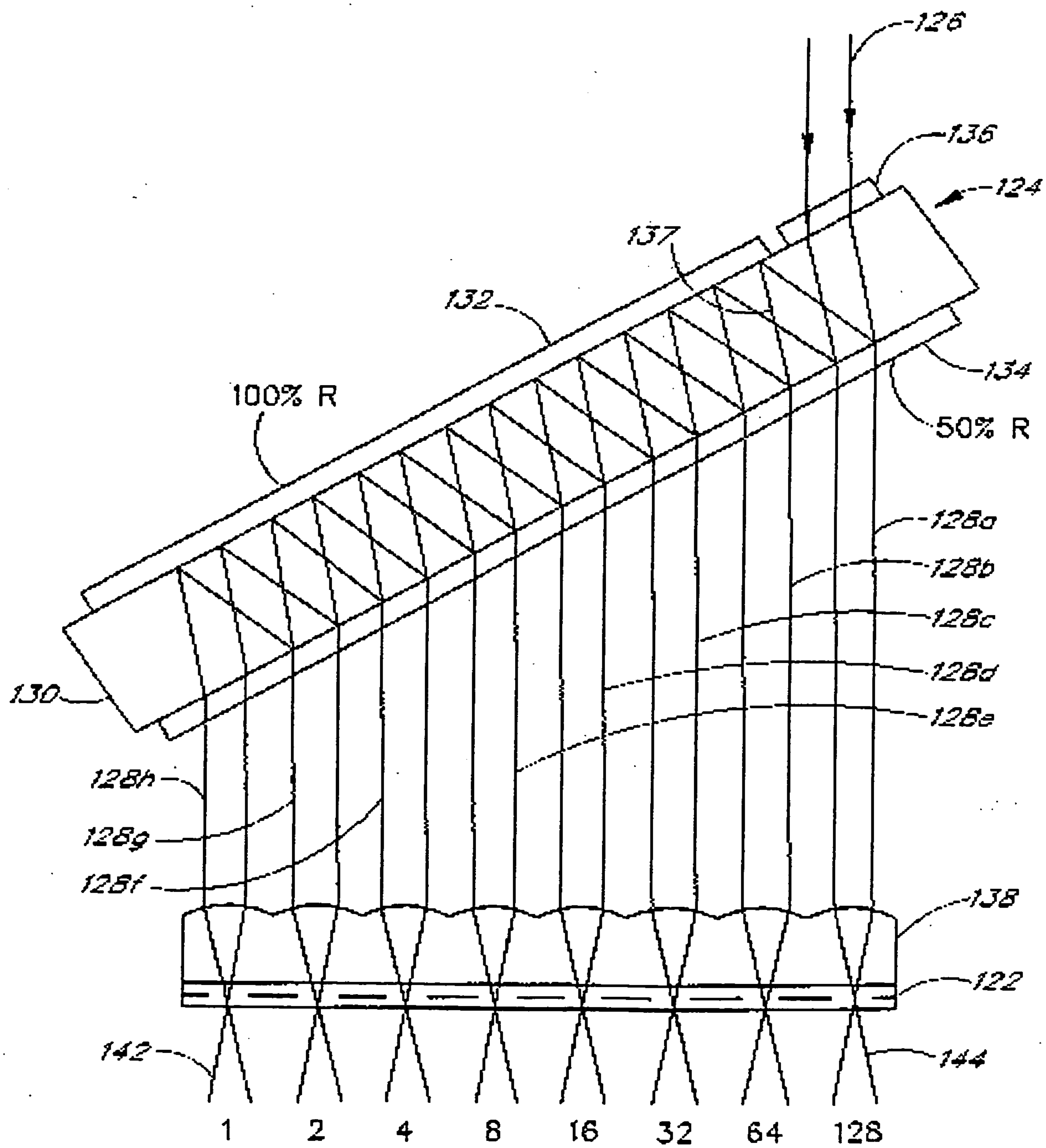

126
136
124
137
132
134
100% R
50% R
128a
128b
128c
128d
128e
130
128h
128g
128f
138
122
142
144
1
2
4
8
16
32
64
128

FIG. 9

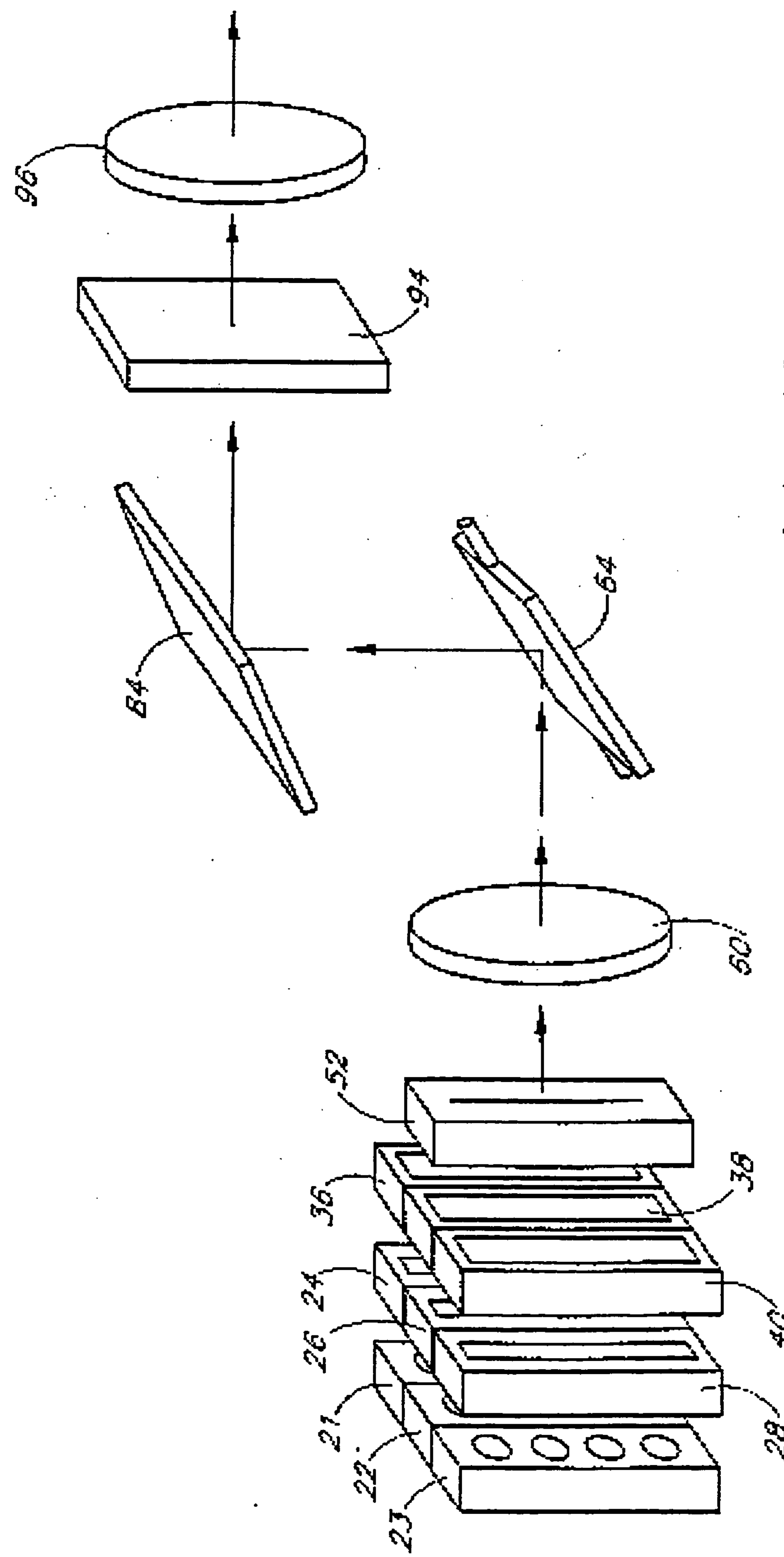


FIG. 10